
# The Potential Global Economic Impact of the Metaverse

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# Executive Summary

This study investigates the potential contribution of the metaverse to global economic activity. The metaverse as conceived today is considered by many a "successor" of the Internet and is sometimes referred to as an "embodied Internet." One way to think about the metaverse is as a set of interconnected digital spaces, including immersive XR experiences that combine the digital and physical words, in which individuals can easily move between different spaces and experiences as well as interact and collaborate with other people who are not in the same physical space. Some of the early components of the metaverse and the experiences and activities it is envisioned to support or enable are already in exhibit, such as augmented reality, virtual reality, mixed reality, blockchain, and non-fungible tokens. These technologies, which are expected to be the backbone of the metaverse and its offerings, are already being used around the world by businesses and creators. As users continue to adopt these technologies, their potential to transform society in unpredictable ways will only accelerate.

Estimating the economic impact of the metaverse presents substantial challenges. Economic theories provide some insights into how new innovations can be expected to evolve and impact economies, but as with all innovations, it is impossible to predict all of the areas in which metaverse technologies will be used, the extent and timing of their adoption, the innovations that will be developed that build upon the metaverse, and all of their associated economic impacts. Put simply, there is no "metaverse" to measure as of today. Yet, rather than wait for some point in the future, we can apply existing tools and data from related sectors, technologies, and consumer behaviors to create a potential analogue for the metaverse. In identifying such an analogue, our goal is not to compare the metaverse to another technology—after all, if the metaverse were similar to an existing technology then it would not be an innovation—but rather, our goal is to learn from the adoption process and economic impact of an existing technology to draw inferences about the potential adoption process and economic impact of the metaverse.

We draw from the deployment and innovation impact of mobile technology to estimate the potential impact of the metaverse. We could in theory use any breakthrough technological innovation as an analogue for the metaverse, but we view mobile technology—which we define to include mobile devices enabled with the Internet and their associated infrastructure and ecosystem[1]—as particularly well suited for a number of reasons. The way mobile technology combined existing technologies such as phones, the Internet, cameras, and mp3 players and evolved to change how we use the Internet is reminiscent of the path the metaverse appears poised to follow. Combining existing technologies such as phones, the Internet, cameras, and mp3 players into a single mobile device fundamentally altered how we connect with the Internet by overcoming limitations of geography. Existing conceptions of the metaverse have a similar flavor of combining existing technologies, such as AR/VR, videoconferencing, multi-player gaming, and digital currency, and turning them into something new. While mobile

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1 We measure mobile technology adoption as the number of active mobile broadband subscriptions per 100 people, sourced from the International Telecommunication Union (ITU). ITU's definition of active mobile broadband subscriptions is as follows: "Active mobile-broadband subscriptions refers to the sum of active handset-based and computer-based (USB/dongles) mobile-broadband subscriptions to the public Internet. It covers actual subscribers, not potential subscribers, even though the latter may have broadband-enabled handsets. Subscriptions must include a recurring subscription fee or pass a usage requirement – users must have accessed the Internet in the last three months. It includes subscriptions to mobile-broadband networks that provide download speeds of at least 256 kbit/s (e.g. WCDMA [(3G)], HSPA [(3G)], CDMA2000 1x EV- DO [(3G)], WiMAX IEEE 802.16e [(4G-level)] and LTE [(4G)]), and excludes subscriptions that only have access to GPRS, EDGE and CDMA 1xRTT." *See* ITU, "WTI Indicators with Definitions," p. 12, available at https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Documents/Events/2017/Aug-aspstat2017/WTI_Indicators_with_Definitions_14Aug2017_final.pdf

devices untethered the Internet from desktop computers, the metaverse is expected to further break down location barriers and transform a wide range of industries by enabling more seamless and immersive experiences as well as creating a sense of presence without the need to be physically present in a location. Similar to mobile technology, the range of expected applications for the metaverse is far-reaching, including the communications, entertainment, education, healthcare, manufacturing, and retail sectors.

Existing research studies define and measure mobile technology in different ways, but collectively they indicate that in a wide range of contexts and across various definitions and measures, mobile technology has had a substantial and beneficial impact on global and local economies, as summarized in **Figure 1**.

**Figure 1. Key Findings from Research on the Economic Impacts of Mobile Technology**

- Mobile technology is associated with a large share of global GDP, accounting for an estimated $4.4 trillion (5.1%) of global GDP in 2020, including direct contributions from mobile operators and the "rest of [the] mobile ecosystem" as well as "[a]dditional indirect and productivity benefits." The mobile ecosystem, as defined by GSMA, includes "handset and device makers, software companies, equipment providers and internet companies, as well as organisations in adjacent industry sectors." Mobile technology's contribution to GDP can be attributed at least partially to new growth in GDP.
- The mobile technology sector directly employed about 12 million people globally—including, for example, direct employment by mobile operators, distributors, and retailers—and indirectly employed another 13 million people globally in adjacent industries in 2020.
- By increasing access to information, mobile technology has reduced price dispersion of agricultural goods and increased welfare in developing countries. Mobile technology has also increased financial inclusion in certain African countries. Here, "mobile technology" refers to mobile phones.
- In addition to creating new jobs and increasing access to information, mobile technology may drive economic growth in undeveloped economies by improving firms' productive efficiency; reducing households' risk by improving communication within their social network; and delivering financial, agriculture, health, and education services via mobile apps and platforms. Here, "mobile technology" refers to mobile phones.
- While many studies indicate that mobile technology has had a net positive economic impact, new technology has the potential to amplify existing inequalities. To mitigate this, research suggests that technological innovations should aim to "amplify already successful development efforts or positively inclined intent" in developing economies.

While it is possible that, like many other previously "hyped" technological innovations, the metaverse never comes to fruition as it is currently envisioned, the goal of our analysis is not to predict whether the metaverse will be successful. Rather, we focus on measuring the potential economic impact of the metaverse if it were to evolve like prior successful technologies in terms of the level and rate of adoption by users and the impact on GDP. The existing research on the economic impacts of mobile technology indicates that if the metaverse were to evolve in a similar way as mobile technology, it could have substantial and beneficial impacts on global and local economies.

To develop empirical estimates of the potential economic impact of the metaverse, we first build on existing literature and estimate the impact of mobile technology on GDP growth using country-level, annual data on: (1)

mobile broadband adoption from the International Telecommunication Union and (2) GDP and a set of control variables from the World Bank, both for the period 2007-2019. Our regression results indicate that a 10% increase in mobile broadband adoption is associated with a 0.087 percentage point increase in GDP growth.

We then apply the same estimated impact of adoption on GDP and the same compound annual growth rate of mobile adoption to obtain an estimate of the metaverse's contribution to GDP after the first 10 years of its adoption. Our main result is that if the metaverse were to be adopted and grow in a similar way as mobile technology, then we would expect it to be associated with a 2.8% contribution to global GDP after 10 years. These numbers represent incremental growth in GDP associated with the metaverse and do not account for any potential displacement of GDP from other industries and sectors that may also occur over time. Regional results are shown in **Figure 2** below.[2]

**Figure 2. Summary of Results**

| Region | Compound Annual Growth Rate of Mobile Adoption | Assumed Secular GDP Growth | Metaverse's Share of 10th Year GDP | Metaverse's Total Contribution to GDP in 2031 ($ Trillions) |
|---|---|---|---|---|
| APAC | 31.2% | 4.3% | 2.3% | $1.04 |
| Canada | 12.2% | 1.1% | 0.9% | $0.02 |
| Europe | 22.6% | 1.5% | 1.7% | $0.44 |
| India | 63.1% | 5.4% | 4.6% | $0.24 |
| LATAM | 66.9% | 1.1% | 5.0% | $0.32 |
| MENAT | 83.9% | 1.9% | 6.2% | $0.36 |
| SSA | 23.5% | 1.0% | 1.8% | $0.04 |
| United States | 29.7% | 1.6% | 2.3% | $0.56 |
| Global | 23.3% | 2.0% | 2.8% | $3.01 |

If we assume that metaverse adoption were to begin today, in 2022, then we can also estimate the metaverse's potential contribution to GDP in dollars and compare it to industry projections of the potential size of the metaverse. Our model implies that if metaverse adoption began today, it would have a contribution to global GDP of $3.01 trillion (measured in 2015 U.S. dollars) in 2031. This estimate lies within the range of existing industry projections, which include estimates ranging from $800 billion to $2 trillion over the next few years, which tend to focus on near-term impacts on gaming, social media, ecommerce, and live entertainment, for example, to long-term estimates ranging from approximately $3 trillion to over $80 trillion.

The extent to which our mobile technology model provides a good estimate of the economic potential of the metaverse depends on how similar the rate and extent of metaverse adoption and its impact ultimately are relative to the rate and extent of mobile technology adoption and its impact. It is impossible to know today whether these assumptions will hold, but we can identify some factors that may contribute to future outcomes. For example, development of the infrastructure and technology required for the metaverse is expected to take time, and building an accessible, inclusive, and safe metaverse is also going to play a vital role in accelerating metaverse adoption

2 For Canada, the compound annual growth rate of mobile adoption and the metaverse's share of 10th year GDP and total contribution to GDP in 2031 are likely understated due to limited data availability. *See* Sections IV–V.

and enabling further development of its innovative technologies. How exactly these types of challenges and opportunities unfold in the coming years will determine the rate of adoption and economic impact of the metaverse.

Furthermore, while our empirical analysis suggests that the metaverse, if successful, has the potential to have a substantial and beneficial impact on the economy in aggregate, the impacts of the metaverse are likely to be felt differently in different sectors of the economy, in different regions, at different points in time, and for different people. Further research is needed to quantify these heterogeneous impacts and to measure the potential displacement of industries and restructuring of local economies that may also accompany the growth of the metaverse.

# I. Introduction

This study investigates the potential contribution of the metaverse to global economic activity. We employ several methods to estimate the metaverse's economic contribution, including econometric analyses, economic literature review, and public sources review.

## A. What is the metaverse?

The metaverse as conceived today is considered by many as a "successor" of the Internet.[3] While there is no agreed upon definition of the metaverse, one way to think about it is as an expansive network of digital spaces, including immersive 3D experiences in augmented, virtual, and mixed reality, that are interconnected and interoperable so you can easily move between them, and in which you can create and explore with other people who aren't in the same physical space as you.[4] Some have referred to the metaverse as an "embodied internet" in which individuals will feel as if they are actually "present" in experiences and not simply looking at experiences through their screens.[5] This means that interacting with the Internet (and the devices that provide access to the

3 *See, e.g.,* Ball, Matthew, "Framework for the Metaverse," matthewball.vc, June 29, 2021, available at https://www.matthewball.vc/all/forwardtothemetaverseprimer ("The Metaverse is best understood as 'a quasi-successor state to the mobile internet'."); Facebook, Inc., "Second Quarter 2021 Results Conference Call," July 28, 2021, pp. 3-4 ("[Mark Zuckerberg, CEO]: So what is the metaverse? It's a virtual environment where you can be present with people in digital spaces. You can kind of think about this as an embodied internet that you're inside of rather than just looking at. We believe that this is going to be the successor to the mobile internet…[W]e also need to make sure we're helping to build ecosystems so millions of other people can participate in the upside and opportunity of what we're all creating…In order for the metaverse to fulfill its potential, we believe that it should be built in a way that is open for everyone to participate."); Meta, "Founder's Letter, 2021," October 28, 2021, available at https://about.fb.com/news/2021/10/founders-letter/.

4 *See, e.g.,* Meta, "Building the Metaverse Responsibly," September 27, 2021, available at https://about.fb.com/news/2021/09/building-the-metaverse-responsibly/ ("The "metaverse" is a set of virtual spaces where you can create and explore with other people who aren't in the same physical space as you. You'll be able to hang out with friends, work, play, learn, shop, create and more."); Design at Meta, "Designing our new company brand: Meta," October 28, 2021, available at https://design.facebook.com/stories/designing-our-new-company-brand-meta/ ("The metaverse is the next evolution of social technology — where you can share immersive experiences with people even when you can't be together in person, and do things together you couldn't do in the physical world."); Ball, Matthew, "Framework for the Metaverse," matthewball.vc, June 29, 2021, available at https://www.matthewball.vc/all/forwardtothemetaverseprimer ("The Metaverse is a massively scaled and interoperable network of real-time rendered 3D virtual worlds which can be experienced synchronously and persistently by an effectively unlimited number of users with an individual sense of presence, and with continuity of data, such as identity, history, entitlements, objects, communications, and payments."); Herrman, John and K. Browning, "Are We in the Metaverse Yet?" *The New York Times,* October 29, 2021, available at https://www.nytimes.com/2021/07/10/style/metaverse-virtual-worlds.html ([Tim Sweeney:] "In the metaverse, you and your friends and your appearance and cosmetics can go from place to place and have different experiences while remaining connected to each other socially."); Cook, John, "We asked seven venture capitalists if the metaverse is the next big thing or just a lot of hype," *GeekWire,* November 23, 2021, available at https://www.geekwire.com/2021/we-asked-seven-venture-capitalists-if-the-metaverse-is-the-next-big-thing-or-just-a-lot-of-hype/; ter Weijde, Rens, "Understanding The Metaverse," Forbes, March 3, 2022, available at https://www.forbes.com/sites/forbestechcouncil/2022/03/03/understanding-the-metaverse/.

5 Ball, Matthew, "Framework for the Metaverse," matthewball.vc, June 29, 2021, available at https://www.matthewball.vc/all/forwardtothemetaverseprimer ("Metaverse iterates further by placing everyone inside an 'embodied', or 'virtual' or '3D' version of the internet and on a nearly unending basis. In other words, we will constantly be 'within' the internet, rather than have access to it, and within the billions of interconnected computers around us, rather than occasionally reach for them, and alongside all other users and real-time. […] The Metaverse is a massively scaled and interoperable network of real-time rendered 3D virtual worlds which can be experienced synchronously and persistently by an effectively unlimited number of users with an individual sense of presence, and with continuity of data, such as identity, history, entitlements, objects, communications, and payments."). *See also* Facebook, Inc., "Second Quarter 2021 Results Conference Call," July 28, 2021, pp. 3-4 ("[Mark Zuckerberg, CEO]: So what is the metaverse? It's a virtual environment where you can be present with people in digital spaces. You can kind of think about this as an embodied internet that you're inside of rather than just looking at. We believe that this is going to be the successor to the mobile internet…[W]e also need to make sure we're helping to build ecosystems so millions of other people can participate in the upside and opportunity of what we're all creating…In order for the metaverse to fulfill its potential, we believe that it should be built in a way that is open for everyone to participate."). *See also* Meta, "Founder's Letter, 2021," October 28, 2021, available at https://about.fb.com/news/2021/10/founders-letter/ ("The next platform will be even more immersive — an embodied internet where you're in the experience, not just looking at it. We call this the metaverse, and it will touch every product we build. The defining quality of the metaverse will be a feeling of presence — like you are right there with another person or in another place.").

Internet) has the potential to be much more natural, incorporating modes of communication that include gesture and voice, such that individuals are not limited to typing or tapping.[6] In addition, the metaverse is envisioned to be able to host almost all the activities we currently take part in (e.g., socializing, work, learning, entertainment, shopping, content creation, etc.) and make new types of activities possible as well.[7]

According to Matthew Ball, a technology expert and venture capitalist, the concept of the metaverse has several characteristics. First, the metaverse is expected to be a continuous experience without pauses and delays, including an unlimited number of users. Second, the metaverse is expected to be an open market, where businesses and individuals would freely engage in activities and generate content and experiences. Third, the metaverse is expected to encompass both the digital and physical worlds and offer an extraordinary "interoperability of data, digital items/assets, content, and so on."[8]

The vision of the future seamless interoperability of the metaverse is very different from what we have now. Today, the digital world remains incompatible. For example, a user is required to have an individual account to access a social media app such as Twitter or TikTok and an individual account to access a gaming console such as Xbox or PlayStation. But in the metaverse a user would be empowered to consume digital goods and services seamlessly.[9] Time Magazine's Andrew Chow supports this vision and writes, "Instead of having separate Facebook and Twitter accounts in which everything you post is owned by those corporations, you will be able to own your digital personhood and all of your ideas and digital belongings wherever you go."[10] For example, an individual could purchase a digital piece of clothing or accessory from a platform and still "wear" it when they visit another platform, as opposed to that digital good being restricted for usage within the platform from which the individual initially purchased it.[11] Evonne Heyning, Co-Chair of the Open Metaverse Interoperability Group, echoes that

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6 Meta, "The Metaverse and How We'll Build It Together -- Connect 2021," [YouTube video], available at https://www.youtube.com/watch?v=Uvufun6xer8, 9:54-10:18.

7 Meta, "The Metaverse and How We'll Build It Together -- Connect 2021," [YouTube video], available at https://www.youtube.com/watch?v=Uvufun6xer8, 1:09-1:33; Ball, Matthew, "Framework for the Metaverse," matthewball.vc, June 29, 2021, available at https://www.matthewball.vc/all/forwardtothemetaverseprimer ("Overall, The Metaverse will significantly broaden the number of virtual experiences used in everyday life (i.e. well beyond video games, which have existed for decades) and in turn, expand the number of people who participate in them.").

8 Ball, Matthew, "The Metaverse: What It Is, Where to Find it, and Who Will Build It," matthewball.vc, January 13, 2020, available at https://www.matthewball.vc/all/themetaverse.

9 Ball, Matthew, "The Metaverse: What It Is, Where to Find it, and Who Will Build It," matthewball.vc, January 13, 2020, available at https://www.matthewball.vc/all/themetaverse. *See also* Radoff, Jon, "Web3, Interoperability and the Metaverse," *Medium*, November 22, 2021, available at https://medium.com/building-the-metaverse/web3-interoperability-and-the-metaverse-5b252dc39da ("Right now, you probably use Facebook Login or Google Login to interact with a large number of online applications. … An important part of Web3 is inverting this model: instead of having a company own your identity and then granting you access to other applications — you will own your identity and choose which applications to interact with. This is accomplished by using a digital wallet such as Metamask (for Ethereum and ETH-compatible blockchains) or Phantom (used on the Solana blockchain). Your wallet becomes your identity, which can then allow you to use various decentralized applications on the internet that need to interact with your currencies and property. This includes decentralized finance applications — as well as metaverse experiences that will draw upon interoperable avatars, items for self-expression, game items, etc.").

10 Chow, Andrew R., "Why TIME Is Launching a New Newsletter on the Metaverse," Time, November 18, 2021, available at https://time.com/6118513/into-the-metaverse-time-newsletter/.

11 *See, e.g.,* Meta, "The Metaverse and How We'll Build It Together -- Connect 2021," [YouTube video], available at https://www.youtube.com/watch?v=Uvufun6xer8, 6:32-7:17 ("Importantly, you should be able to bring your avatar and digital items across different apps and experiences in the metaverse."); 37:48-37:55 ("And most importantly, there'll be a real sense of continuity, where the things you buy are always available to you").

interoperability is what sets the metaverse apart: "the metaverse isn't a single firm or organization's product or space, or even all of them together — it's the way they're connected."[12]

In addition to collaboration and technological advances on a massive scale, the metaverse is going to require elevated user experience, sophisticated telecoms infrastructure, and human-machine interfaces. Some of these components are well advanced already, while others still need to be created and developed. Augmented reality (AR),[13] virtual reality (VR),[14] mixed reality (MR),[15] extended reality (XR),[16] blockchain,[17] and non-fungible tokens (NFTs or "tokens")[18] are fledgling technologies of today that are expected to be the backbone of the metaverse or of social and economic activity within the metaverse—for example, blockchain and NFTs are expected to play a central role in the exchange of digital goods within the metaverse.[19] **Figure 3** previews some examples of how these component technologies are in use today. Additional examples of use cases for regions around the world are described in the next section.

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12 Herrman, John, and Browning, Kellen, "Are We in the Metaverse Yet?" The New York Times, October 29, 2021, available at https://www.nytimes.com/2021/07/10/style/metaverse-virtual-worlds.html/.

13 Augmented reality ("AR") is a real-world environment combined with computer-generated sensory input such as sound, video, and graphics, and is designed to enhance a person's perception of reality by overlaying the real world with additional information. *See, e.g.,* IGI Global, 'What is Augmented Reality," available at https://www.igi-global.com/dictionary/augmented-reality/1858.

14 Virtual reality ("VR") describes a three-dimensional, computer-generated environment in which a person can become immersed and explore and interact with their surroundings. *See, e.g.,* Virtual Reality Society, "What is Virtual Reality?" available at https://www.vrs.org.uk/virtual-reality/what-is-virtual-reality.html.

15 Mixed reality ("MR") is a blend of physical and digital worlds, unlocking natural and intuitive 3D human, computer, and environmental interactions. This new reality is based on advancements in computer vision, graphical processing, display technologies, input systems, and cloud computing. *See, e.g.,* SeniorCare2Share, "What is Mixed Reality," available at https://www.seniorcare2share.com/what-is-mixed-reality/; CaesarVR, "What is Mixed Reality?" available at https://www.caesarvr.com/vr-ar-news/what-is-mixed-reality.

16 Extended reality ("XR") is an umbrella term that combines VR, AR, and MR. *See, e.g.,* Gerencer, Tom, "What is Extended Reality (XR) and How Is it Changing the Future?" *hp,* April 3, 2021, available at https://www.hp.com/us-en/shop/tech-takes/what-is-xr-changing-world; North of 41, "What really is the difference between AR/MR/VR/XR?" *Medium,* March 20, 2018, available at https://medium.com/@northof41/what-really-is-the-difference-between-ar-mr-vr-xr-35bed1da1a4e.

17 Blockchain is a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network. Assets transacted and tracked in blockchain can be tangible—such as a house, car, cash, or land—or intangible—such as intellectual property, patents, copyrights, or branding. Virtually anything of value can be tracked and traded on a blockchain network, reducing risk and cutting costs for all involved. *See, e.g.,* IBM, "What is blockchain technology?" available at https://www.ibm.com/topics/what-is-blockchain.

18 Non-Fungible Tokens (NFTs) are an example of a digital good that has real-world value. NFTs represent real-life assets and are not duplicable, unlike other digital assets such as a .jpg file, where a copy is indistinguishable from the original. NFTs are stored on public-facing digital ledgers called blockchain. *See, e.g.,* Kaczynski, Steve and S. D. Kominers, "How NFTs Create Value," *Harvard Business Review,* November 10, 2021, available at https://hbr.org/2021/11/how-nfts-create-value; Conti, Robyn and J. Schmidt, "What Is An NFT? Non-Fungible Tokens Explained," *Forbes Advisor,* February 15, 2022, available at https://www.forbes.com/advisor/investing/nft-non-fungible-token/.

19 Blockchain, along with the variety of cryptocurrencies it can support, is already being used to purchase digital goods and assets in existing virtual platforms and could continue supporting digital goods transactions in the metaverse. Beyond individual purchases, the decentralized nature of blockchain-based finance is believed to be well suited for economic activity within a metaverse that is envisioned as a decentralized, interoperable network of virtual worlds and environments. NFTs, built upon blockchain, are envisioned to assign value to digital objects as well as represent and/or prove rights of ownership, usage, etc. to a digital environment or asset. *See* Marr, Bernard, "The Important Links Between NFTs, Blockchain, And The Metaverse," *Bernard Marr & Co,* November 30, 2021, available at https://bernardmarr.com/the-important-links-between-nfts-blockchain-and-the-metaverse/. In addition, community-driven content and user-generated content, in which NFTs currently play prominent roles, are expected to become more important in the metaverse. *See* Radoff, Jon, "The Metaverse Value-Chain," April 7, 2021, available at https://medium.com/building-the-metaverse/the-metaverse-value-chain-afcf9e09e3a7; Herrman, John, and Browning, Kellen, "Are We in the Metaverse Yet?" The New York Times, October 29, 2021, available at https://www.nytimes.com/2021/07/10/style/metaverse-virtual-worlds.html/. *See also,* Ball, Matthew, "Framework for the Metaverse," matthewball.vc, June 29, 2021, available at https://www.matthewball.vc/all/forwardtothemetaverseprimer ("Personally, I'm tracking the emergence of the Metaverse around eight core categories […] You'll note 'crypto' or 'blockchain technologies' are not a category. Rather, they span and/or drive several categories, most notably compute, interchange tools and standards, and payments — potentially others as well.").

**Figure 3. Example Uses of Metaverse-Related Technologies[20]**

- The popular mobile app Nintendo's Pokémon Go, where users catch their favorite Pokémon by looking through their phones at the real world but with superimposed images, reflected mass adoption of AR technologies.
- VR headset Oculus Quest 2 enables users to play games such as Beat Saber and exercise in simulated sports like virtual boxing.
- Japan Airlines has trained flight engineers remotely using Microsoft HoloLens, MR smartglasses developed and manufactured by Microsoft, which has reduced training and travel time, as engineers do not need to wait for an available plane or travel to the hangar.
- XR technologies in the form of Google Maps and interactive Zoom backgrounds are improving how millions of people navigate streets and communicate at work every day.
- NFTs empower creators to monetize their unique products—for example, a work of art called "Everydays: The First 5000 Days" was sold for a record $69 million at Christie's Auction House as a non-fungible token in March of 2021.
- Cryptocurrencies based on blockchain technology, such as Bitcoin and Ethereum, and cryptocurrency transfer apps, such as Coinbase Commerce and Electroneum, are changing global payment ecosystems.

So, some of the early components of the metaverse are already in exhibit – but in bits and pieces. And these components are already having significant societal, commercial, and business impacts. As users continue to adopt these technologies, their potential to transform society in unpredictable ways will only accelerate. In the long run, the metaverse's reach could extend well beyond things we can conceive of today, becoming integrated with traditional businesses, creating new jobs, and affecting consumers in new ways.

## B. Uses of metaverse technologies around the world

An anticipated benefit of the metaverse is the creation of new markets and broader economic and social impacts. As with the Internet and other technologies, the form and shape of the metaverse will materialize slowly at first, and only after a critical mass of adoption is achieved, will its full potential begin to take more concrete shape.[21] In

20 Robertson, Adi, "Oculus Quest 2 Review: Better, Cheaper VR," The Verge, available at https://www.theverge.com/21437674/oculus-quest-2-review-features-photos; Microsoft, "Japan Airlines creates yet another first-class experience, this time using Microsoft HoloLens," available at https://news.microsoft.com/transform/japan-airlines-creates-yet-another-first-class-experience-this-time-using-microsoft-hololens/; Gerencer, Tom, "What Is Extended Reality (XR) and How Is it Changing the Future?" HP Tech Takes, April 3, 2021, available at https://www.hp.com/us-en/shop/tech-takes/what-is-xr-changing-world/; Kaczynski, Steve, and Kominers, Scott Duke, "How NFTs Create Value," Harvard Business Review, November 10, 2021, available at https://hbr.org/2021/11/how-nfts-create-value/.

21 As an illustration of the time it can take to achieve widespread adoption of a new technology, in 2011 only 35% of adult Americans owned a smartphone; whereas, ten years later in 2021, 85% of adult Americans now own a smartphone. See Pew Research Center, "Mobile Fact Sheet," April 7, 2021, available at https://www.pewresearch.org/internet/fact-sheet/mobile/. See also Van Slyke et al., "Perceived critical mass and the adoption of a communication technology," European Journal of Information Systems, Vol. 16, No. 3, July 2007, pp. 270-283 ("Critical mass influences the adoption and diffusion of interactive communication innovations, both through network externalities and through sustainability of the innovation.").

this section, we look at a few use cases around the globe that illustrate the potential broader impacts the metaverse could have on society.

In the United States, metaverse technologies are currently expanding access to sports, helping combat biases via simulations, and merging physical and virtual worlds in gaming. For example, iGYM is an AR system for inclusive play that was created to give young people with mobility disabilities access to physical play activities with their non-disabled peers.[22] In bias training, the Lab for Applied Social Science Research (LASSR) at the University of Maryland created a training program for law enforcement personnel that includes immersive VR simulations in which police officers interact with civilians in different policing situations.[23] LASSR uses the simulator to measure how officers' decisions and the content of their speech vary by civilian demographics, such as race and gender. And in gaming, Roblox, founded in 2004, accommodates thousands of games and experiences such as Bloxburg and Brookhaven, where users can build homes, work, and play out scenarios.[24] Additionally, in November 2021, Roblox and Nike announced a partnership to host "Nikeland," which comprises a selection of product showrooms and play areas on Roblox in which users can outfit their avatar in classic Nike products like the Air Force 1 and Nike Blazer.[25]

In Canada, AR and VR technologies are changing the way people view and experience art. Toronto-based company Nextech AR partnered with Culture Mile and Brookfield Properties in London to build "the Harmony at London Wall Place," a major AR virtual experience featuring visuals and music from the Guildhall School of Music and Drama as well as the London Symphony Orchestra.[26] Visitors can open a camera on their phones and hear music compositions and see an AR art installation featuring 3D animation overlaid onto the feed of the camera.

In Europe, industrial companies are adopting XR technologies to simplify and streamline prototyping, training, remote guidance, and customer relationship processes. Siemens, a German industrial manufacturing company, offers a VR product for product design and prototyping called Teamcenter VR.[27] The ability to change the design and characteristics of the prototype in 3D has the potential to bring significant time and cost savings, as iterating in 3D reduces both raw materials and production time. Professional industrial training also stands to benefit from VR applications—BMW, Peugeot, and Audi are among the early adopters of industrial VR training, which has been shown to reduce training budgets without reducing quality.[28] Employees are more engaged, while training is safer

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22 iGYM resembles a life-size air hockey field. When players enter the field, an overhead computer vision camera detects each player and surrounds them with a "peripersonal circle," which players use to hit a projected ball. Players can widen their circle to hit the ball by moving their arms, physically kicking, or by pressing a "kick-button" mounted on their body, allowing for an equitable play experience for kids with mobility disabilities and their peers without disabilities. *See* iGYM, "Building a future where play and exercise are inclusive and fun for people of all abilities," available at https://www.igym.solutions/.

23 Lab for Applied Social Science Research, "Train the Trainer," p. 7.

24 Snider, Mark, and Molina, Brett, "Everyone wants to own the metaverse including Facebook and Microsoft. But what exactly is it?" USA Today, December 22, 2021, available at https://www.usatoday.com/story/tech/2021/11/10/metaverse-what-is-it-explained-facebook-microsoft-meta-vr/6337635001/.

25 Greener, Rory, "Nike, Roblox Debut 'NIKELAND' Metaverse," XRToday, November 22, 2021, available at https://www.xrtoday.com/mixed-reality/nike-roblox-debut-nikeland-metaverse/e; Nike, "Nike Creates NIKELAND on Roblox," November 18, 2021, available at https://news.nike.com/news/five-things-to-know-roblox.

26 Cureton, Demond, "Nextech AR Rebrands as Metaverse Company," XR Today, November 16, 2021, available at https://www.xrtoday.com/augmented-reality/nextech-ar-rebrands-as-metaverse-company/.

27 Siemens, "Go VR for Fully Immersive Design Experience Virtual Reality with PLM," available at https://www.plm.automation.siemens.com/global/en/products/collaboration/virtual-reality.html/.

28 VR Owl, "The 22 best examples of how companies use virtual reality for training," available at https://www.vrowl.io/news/the-22-best-examples-of-how-companies-use-virtual-reality-for-training/.

and more effective, as it is possible to conduct safety drills in VR without compromising on the experience while avoiding potentially dangerous conditions.

In the Middle East, Dubai, a host for the 2020 World Expo,[29] has embraced metaverse technologies and opened its doors to virtual visitors from all over the world through the Expo Dubai Xplorer multiplayer experience.[30] The Expo Dubai Xplorer allows virtual visitors to enjoy views of an interactive “digital twin” of the Expo site via AR spectacles synchronized with the real-world locations within the physical Expo through March 2022. According to Magnopus, a content-focused technology company, Expo Dubai Xplorer sets a new standard for accessibility and inclusivity in large events.[31]

In Africa, Africarare—referred to as “the first South African metaverse”—launched in October 2021.[32] Africarare represents a digital land, Ubuntuland, and offers immersive VR experiences including a marketplace for art. Africarare featured the premiere NFT art collection from the well-known South African artist Norman Catherine.[33] After his debut NFT art collection sold out, the artist commented, “NFTs have opened up a whole new medium for artists to explore. This is a new era of investment art.”[34] Africarare users can purchase land via $UBU Coin, create avatars, and engage in social, gaming or art experiences, and new Africarare NFT collections will continue to be featured.[35] Notably, Africa’s largest mobile network operator, MTN Group, announced in February 2022 that it had purchased 144 plots of virtual land in Ubuntuland and that MTN was the first African company to invest in the metaverse.[36]

In Latin America, Brazilian company MondoDX created the first XR platform for online retail shopping, VYRCH.[37] VYRCH allows customers to visit a virtual store where they can walk around, pick-up items, try them on, speak to a shopping assistant, and more.[38] VYRCH has experienced a higher customer conversion rate than standard online stores, which is attracting a lot of interest from retailers. Quipu Market, an e-commerce platform registered in Colombia and the U.S., provides an online, mobile platform that allows individuals and microbusinesses in low-

29 Bureau International des Expositions, “What is Expo?” available at https://www.bie-paris.org/site/en/what-is-an-expo/. (“Expos are global events dedicated to finding solutions to fundamental challenges facing humanity by offering a journey inside a chosen theme through engaging and immersive activities. Organised and facilitated by governments and bringing together countries and international organisations (Official Participants), these major public events are unrivalled in their ability to gather millions of visitors, create new dynamics and catalyse change in their host cities.”).

30 NewsDirect, “Expo 2020 Dubai Enters The Metaverse World Connecting Millions Across The Physical & Digital Globally,” December 7, 2021, available at https://newsdirect.com/news/expo-2020-dubai-enters-the-metaverse-world-connecting-millions-across-the-physical-and-digital-globally-652848762/ (“Expo 2020 Dubai”).

31 Expo 2020 Dubai.

32 Africa.com, “First African Metaverse Launches,” October 11, 2021, available at https://www.africa.com/first-african-metaverse-launches/.

33 Africa.com, “First African Metaverse Launches,” October 11, 2021, available at https://www.africa.com/first-african-metaverse-launches/.

34 Moloi, Thabiso, “Africarare Is Now The First Sold Out African Metaverse Collection,” BWTH Blog, available at https://bandwidthblog.co.za/2021/10/25/africarare-is-now-the-first-sold-out-african-metaverse-collection/.

35 Africa.com, “First African Metaverse Launches,” October 11, 2021, available at https://www.africa.com/first-african-metaverse-launches/.

36 *See, e.g.,* Oluwole, Victor, “Africa’s largest mobile network operator MTN Group buys 144 plots of virtual land in the metaverse,” *Business Insider Africa,* March 1, 2022, available at https://africa.businessinsider.com/local/markets/africas-largest-mobile-network-operator-mtn-group-buys-144-plots-of-virtual-land-in/1plhh70; Roberts, Lillian, “Africa Launching Into The Metaverse,” *Forbes Africa,* March 2022, available at https://www.forbesafrica.com/technology/nft/2022/03/10/africa-launching-into-the-metaverse/.

37 Tayler, Victoria, “Latin American developers of the innovative AR/VR VYRCH shopping platform join the Nonvoice Agency,” June 21, 2021, available at https://www.nonvoice.com/vyrch-shopping-platform-join-the-nonvoice-agency/ (“AR/VR VYRCH”).

38 AR/VR VYRCH.

income communities to conduct business and perform transactions using virtual tokens, thereby helping these businesses build creditworthiness despite lack of access to formal banking.[39]

In East Asia, the metaverse is drawing attention and investment from major digital platform and gaming companies, the entertainment industry, and even governments. In South Korea, major gaming company Krafton and internet conglomerate Naver are partnering to jointly develop a "user-generated NFT metaverse platform."[40] Naver has already developed Zepeto, a social gathering and digital good shopping platform that boasts over 200 million users globally. Zepeto is reminiscent of Roblox and features virtual stores and user-generated content, as well as partnerships with celebrities. The K-pop industry is involved with metaverse-related platforms including Zepeto and Fortnite, with popular K-pop groups utilizing these platforms to launch songs and interact with fans.[41] Seoul's government also announced in late 2021 that it plans to develop its own metaverse-related platform by the end of 2022 and have the platform be fully operational in 2026.[42]

In India, TardiVerse, a Chennai-based startup, is making headlines for enabling India's first metaverse marriage.[43] Developed based on Polygon Technology Blockchain and led by Vignesh Selvaraj, TardiVerse announced in January 2022 that they are planning to host a couple's wedding reception in the metaverse.[44] The digital reception will be Hogwarts-themed, and accessible to friends and family of the couple from around the world, and the guests will be able to choose their avatars. According to XROM, a Mumbai-based Extended Reality venture, there are over 2,000 AR/VR startups in India that will drive economic growth in the near future.[45]

## C. Challenges of measuring the economic impact of the metaverse

The many use cases of existing technologies that are expected to transfer to the metaverse give us some indication of the potential reach of the metaverse. However, estimating the economic impact of the metaverse presents substantial challenges.

Researchers commonly measure economic impacts of various technologies by collecting data on measurable outcomes that have already occurred and can be analyzed using economic models. However, assessing the economic impact of an emerging technology like the metaverse is much more difficult because outcomes have not yet been realized and cannot be observed in data. It is impossible to predict, *a priori*, all of the areas in which metaverse technologies will be used, the extent of adoption of the metaverse, the innovations that will be

39 Bluestein, Adam, "The 10 most innovative companies in Latin America in 2022," *Fast Company,* March 8, 2022, available at https://www.fastcompany.com/90724423/most-innovative-companies-latin-america-2022; Quipu Market, [LinkedIn profile], available at https://www.linkedin.com/company/quipumarket/.

40 Lam, Eunice, "South Korean Game Maker Krafton Joins Metaverse, NFT Craze," *Forbes,* February 9, 2022, available at https://www.forbes.com/sites/eunicelam/2022/02/09/south-korean-game-maker-krafton-joins-metaverse-nft-craze/?sh=77b814816052.

41 Kim, Sang, "South Korea's Approach to the Metaverse," *The Diplomat,* November 2, 2021, available at https://thediplomat.com/2021/11/south-koreas-approach-to-the-metaverse/.

42 Squires, Camille, "Seoul will be the first city government to join the metaverse," *Quartz,* November 9, 2021, available at https://qz.com/2086353/seoul-is-developing-a-metaverse-government-platform/.

43 Brabus, Paul, "India's First Metaverse Marriage Scheduled on February 6th in TardiWorld," *The VR Soldier*, January 20, 2022, available at https://thevrsoldier.com/first-metaverse-marriage-scheduled-in-tardiworld/.

44 Raju, Chithira N., "Tamil Nadu couple to host India's first wedding reception in Metaverse," The Indian Express, January 18, 2022, available at https://indianexpress.com/article/trending/trending-in-india/tamil-nadu-couple-to-host-wedding-reception-in-metaverse-7728255/.

45 Avil, Eddie, "Virtual Reality Startups in India Everyone Needs to Know About - Top 10 XR Startups from India," XROM, March 21, 2021, available at https://www.xrom.in/post/virtual-reality-startups-in-india-everyone-needs-to-know-about-top-10-xr-startups-from-india ("Back in 2015 India had less then 10 virtual reality startups, today we have over 2000 + AR/VR Startups in the country […]").

developed that build upon the metaverse, and all of their associated economic impacts. Similarly, it is not possible to quantify all of the displacement effects of the metaverse to derive the net economic impact.

Put simply, there is no “metaverse” to measure as of today. Rather than wait for some point in the future, we can apply existing tools and data, such as related sectors, technologies, and consumer behaviors to create a potential analogue for the metaverse’s impact. While imperfect, this provides a transparent framework by which to grasp the potential impact and reach of the metaverse.

To measure the potential economic impact of the metaverse, we use mobile technology as a plausible analogue for our exercise. While there are a number of possible existing technologies to draw from, we focus on mobile technology in part due to its maturity, global reach, and especially its transformative impact on businesses, people and society. In Section III we provide further details about the benefits of relying on mobile technology to draw comparisons for the metaverse.

We examine the existing economic literature on the impacts of mobile technology on GDP, employment, economic inequality, and other economic indicators, and we present an empirical approach to measure the economic impact associated with mobile technology for different regions over time. We then use insights from this analysis to quantify the potential economic impact of the metaverse. Our main result is that if the metaverse were to be adopted and grow in a similar way as mobile technology, then we would expect it to be associated with a 2.8% contribution to global GDP after 10 years.

The rest of this paper is organized as follows. Section II discusses certain theoretical underpinnings in the economics of innovation and examines a range of breakthrough technologies of the past century and their economic impacts. Section III discusses why we focus on mobile technology as an analogue for the metaverse and reviews existing research on the economic impacts of mobile technology. Section IV develops our empirical model of the relationship between mobile technology adoption and GDP growth, and Section V applies the mobile technology model to estimate the potential impact of the metaverse on GDP. Section VI concludes the paper and invites future research regarding the potential economic opportunity of the metaverse.

# II. Economics of Innovation

Measuring the impact of any technological innovation is hard, and especially so during its early stages of development. As with all innovations before, the metaverse will likely have multiple phases of evolution, making predictions about its economic impact particularly difficult and complex. While the future is inherently uncertain, economic theories related to the diffusion and impacts of new technologies can provide helpful insights to guide inferences about how the metaverse may evolve, even at this early stage in its development.

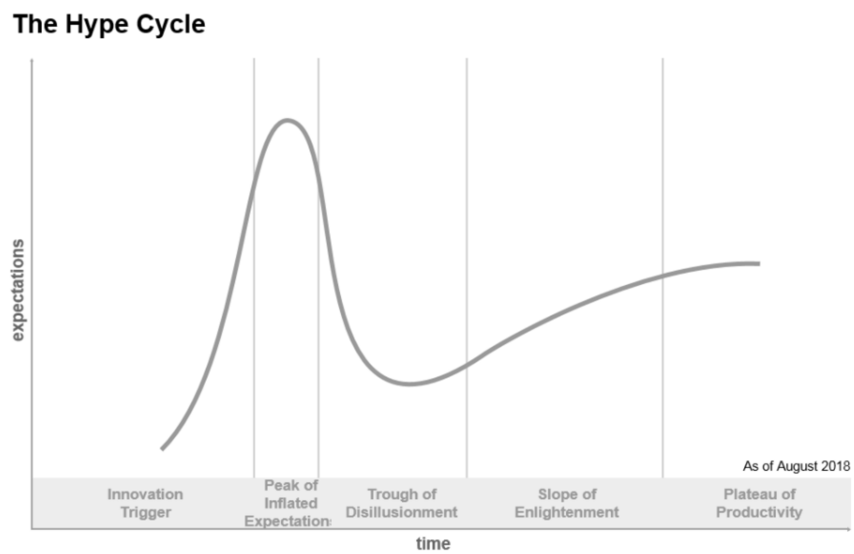
## A. Theories of innovation

Two concepts related to technological innovation—hype cycles and S-curves—provide a helpful starting point for thinking about the potential success and diffusion of a new technology. These concepts are also useful for establishing the building blocks for ongoing research and conversations, rather than being final or definitive.

### *1. Hype cycles*

The research and advisory company Gartner publishes yearly "Hype Cycles and Priority Matrices" reports that attempt to categorize new technologies in terms of their promise in coming to market.[46] An analysis of these hype cycles from 2000 to 2016 shows that the majority of "hyped" technologies never successfully land in the market, illustrating a mismatch between initial expectations and ultimate market adaptation. Furthermore, even for technologies that do successfully land in the market, retrospective analysis shows that they tend to go through multiple phases of expectations of success from consumers, producers, and other market participants.

**Figure 4. The Hype Cycle**




Source: Gartner.

**Figure 4** illustrates the phases of a hype cycle for a successful technology.[47] An innovation's hype cycle starts with an "Innovation Trigger" that provokes development and interest in the innovation. As the "buzz" around the innovation builds, it becomes a central topic of discussion, and the market is flooded with overlapping, competing, and complementary offerings. This leads to overly high expectations around the innovation's capabilities and can lead to the formation of an investment bubble. At this point, the innovation has reached the "Peak of Inflated Expectations." However, as people become impatient for results, the innovation fails to meet these expectations and reaches the "Trough of Disillusionment." Performance issues, slow adoption, or inability to produce financial benefits in the anticipated time frame leads to disillusionment with the innovation, and producers may fail or consolidate due to insufficient demand growth. After the trough, the innovation matures as producers continue iterating on and improving products and best practices for innovation adoption become more widely known. As the innovation progresses through this "Slope of Enlightenment" phase, its market penetration grows from around 5% to approximately 20% to 30%. Adoption of the innovation becomes mainstream as the innovation reaches the

46 Blosch, Marcus and Jackie Fenn, "Understanding Gartner's Hype Cycles," *Gartner Research*, August 20, 2018, ("Gartner"), available at https://www.gartner.com/en/documents/3887767.

47 Gartner.

"Plateau of Productivity." At this stage, hype around the now-mature innovation has been replaced by well-developed application and deployment knowledge and experiences. In addition, an "ecosystem" of products and services may develop around the innovation, which can trigger additional spin-off hype cycles for the components themselves.

The hype cycle framework has a couple implications for our analysis. First, it is possible that, like many other previously "hyped" technological innovations, the metaverse never comes to fruition as it is currently envisioned. But our goal is not to predict whether the metaverse will be successful. Rather, we focus on measuring the potential economic impact of the metaverse if it were to evolve like prior successful technologies. Second, the hype cycle suggests that marketplace expectations at any given point in time are not a good proxy for the economic impact of the metaverse in the long-run. If successful, the metaverse stands to be overhyped at first, followed by an over-negative correction, before finding its niche in productivity and utility. Pinpointing where in the cycle we currently are is inherently difficult, if not impossible. Third, even if the metaverse succeeds, the hype cycle framework does not predict the time periods for the various stages of the hype cycle. Our approach is therefore based on an analysis of prior technologies that have already gone through the phases of the hype cycle and have reached the stable "plateau of productivity," at which point we can start to assess their long-run impacts based on observed outcomes.

### *2. S-curves*

The S-curve is another useful tool that helps us understand how a given technology evolves and how it is eventually overtaken by newer innovations, such as the shift from desktop to mobile devices.[48]

Each new technology tends to follow an S-shaped curve that reflects an initial period of seemingly slow innovation and adoption, followed by a period of rapid change, and then a leveling off as the market matures, as shown in each of the solid lines in **Figure 5** below.[49] Over time, as new innovations are developed, the S-curves of different technologies tend to build on top of each other, allowing for continued improvement in performance, shown by the dotted line in **Figure 5**. For example, personal computers, the Internet, and smartphones each have their own S-curves, but when viewed together over time, they have tended to continually increase the performance of products in the information and communications technology (ICT) sector. On a recent episode of "The Indicator" from NPR's Planet Money podcast, independent tech industry analyst Benedict Evans discussed that artificial intelligence, AR, VR, and cryptocurrencies are some of the next potential candidates that may be at the early stages of their S-curves.[50]

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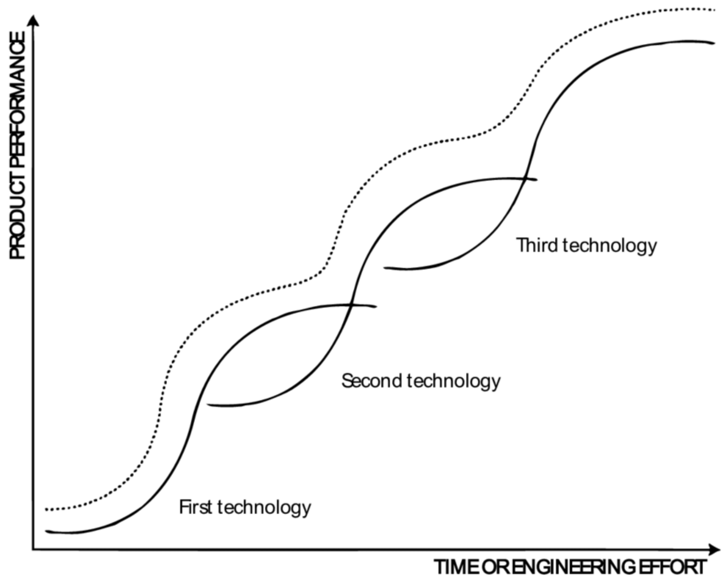
48 *See, e.g.,* Gal's Insights, "The Innovation S-Curve," July 25, 2015, available at http://www.galsinsights.com/the-innovation-s-curve/.

49 *See, e.g.,* Benedict Evans, "The end of smartphone innovation," available at https://www.ben-evans.com/benedictevans/2017/3/22/the-end-of-smartphone-innovation.

50 NPR, "Technology brought to you by the s-curve," Podcast, October 6, 2021, available at https://www.npr.org/2021/10/06/1043822817/technology-brought-to-you-by-the-s-curve.

**Figure 5. S-Curves**




Source: Clayton M. Christensen, "Exploring the Limits of the Technology S-Curve. Part 1: Component Technologies," *Production and Operations Management*, Vol. 1(4), 1992.

Although society experiences ongoing innovation (the dotted line in **Figure 5**), S-curves reflect how individual products and technologies go through their own lifecycles, eventually becoming obsolete as they are replaced by new products and technologies. The transition from one curve to the next relies on innovations that are compatible with existing technologies, but over time newer innovations tend to make previous technologies obsolete—for example, CDs cannot be played on iPhones. Soren Kaplan, Managing Principal of boutique innovation consulting firm InnovationPoint, writes, "S-curves are usually connected to 'market adoption' since the beginning of a curve relates to the birth of a new market opportunity, while the end of the curve represents the death, or obsolescence of the product, service, or technology in the market. Usually the end of one S-curve marks the emergence of a new S-curve – the one that displaces it (e.g., video cassette tapes versus DVDs, word processors versus computers, etc.)."[51]

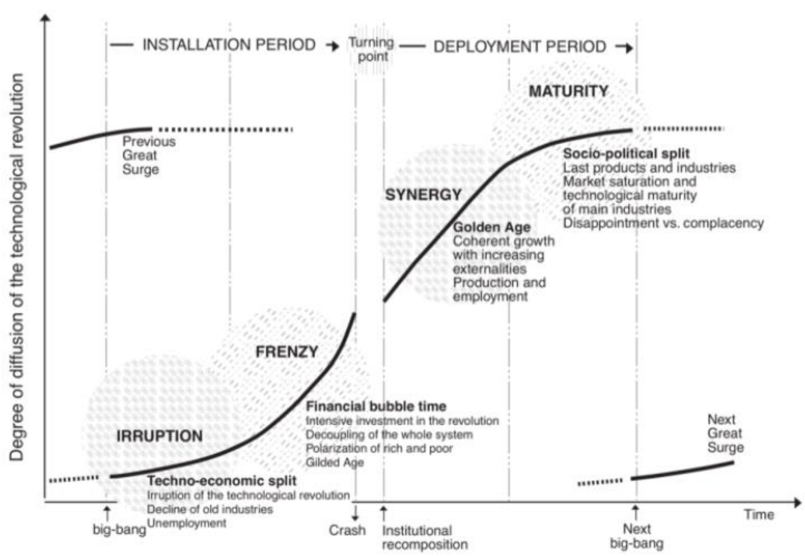
While **Figure 5** suggests potentially unbounded growth in performance associated with continued innovation, the concept of the S-curve may also apply on a very large scale. Carlota Perez, a scholar who specializes in technology and socio-economic development, argues that large-scale technological revolutions over the past 250 years—including those associated with the Industrial Revolution (1771–1829), steam and railways (1829–1873), steel and heavy engineering (1875–1918), oil, automobiles and mass production (1908–1974), and ICT (1971–present)—all share similar patterns, with every technological revolution experiencing an "Installation Period," a

51 Kaplan, Soren, "Leveraging market, technology, and organizational S-curves to drive breakthrough growth," *InnovationPoint*, available at https://www.innovation-point.com/wp-content/uploads/2017/02/Innovation_Lifecycles.pdf.

"Turning Point," and a "Deployment Period" that together follow the shape of an S-curve over a very long time horizon.[52]

**Figure 6** illustrates Perez's theory. According to Perez, the Installation period is "the time when the new technologies irrupt in a maturing economy and advance like a bulldozer disrupting the established fabric and articulating new industrial networks, setting up new infrastructures and spreading new and superior ways of doing things."[53] During the Turning Point, the financial bubble associated with the "Frenzy" of the latter part of the Installation period collapses, causing a recession or even a depression, which leads to institutional restructuring and innovation in policy as institutions begin regulating behavior that led to the formation of the bubble. The "Synergy" phase is then characterized by increased technological stability, fewer business failures, higher and more prolonged employment, and less economic inequality as products become cheaper and more user friendly and the technology begins to reach more of the population. Finally, the Maturity phase is characterized by a stagnation in innovation, and investors begin seeking opportunities to invest in new technological systems and paradigms, setting off the next technological revolution.

**Figure 6. Technological Revolution: Degrees of Diffusion**




Source: The Death and Birth of Technological Revolutions.

Perez believes that we are in the Turning Point of the ICT revolution—the most recent technological revolution, which has been enabled by semiconductors, integrated circuits, computers, software, computer networking, and

52 Neumann, Jerry, "The Deployment Age," *Reaction Wheel,* October 14, 2015, ("The Deployment Age"), available at http://reactionwheel.net/2015/10/the-deployment-age.html; Thompson, Ben, "The Death and Birth of Technological Revolutions," *Stratechery,* October 12, 2021, ("The Death and Birth of Technological Revolutions"), available at https://stratechery.com/2021/the-death-and-birth-of-technological-revolutions/.

53 The Death and Birth of Technological Revolutions.

mobile phones.[54] In 2019, Perez tweeted: "I see the present as the 1930s, the turning point of the IT surge. We have had 2 frenzies and we have not yet had a golden age. The power of AI, IoT, 3D, robots, blockchain is there to be shaped."[55]

S-curves have a couple implications for our analysis. First, if the metaverse is successful, we can be reasonably certain that it will follow an S-shaped curve of innovation and adoption. We therefore look to prior technologies to get a sense of the levels and time periods over which those technologies diffused and were adopted to serve as a potential analogue for diffusion and adoption of the metaverse. Second, it is less clear where the metaverse's place may lie in terms of its contribution to a large-scale technological revolution—would it be the second act in the ICT revolution, or the next great technological surge? Although there is no guarantee that what happens next will mirror what happened previously, we must rely on the tools and data currently available. This suggests we look at related sectors, technologies, and consumer behaviors as a benchmark for the potential reach of the metaverse, recognizing that this approach—as with any approach to measuring the future—requires making use of the data and tools currently at our disposal, and then making transparent methodological choices to arrive at an answer.

## B. Economic impact of innovation

Having discussed theories of the diffusion and adoption of new technologies, we now turn to understanding the potential economic impacts of successful technological innovations. In particular, economic growth models are useful in our goal to link technological innovation to how economies can be expected to benefit. Though it is impossible to summarize generations' worth of such research, it is still useful to provide an overview of how the metaverse would be expected to impact the global economy.[56]

### *1. Production possibilities frontier*

Economic theory tells us that successful technological innovation leads to a more efficient allocation of scarce resources. Innovation changes the level and shape of what economists call the "production possibilities frontier" (PPF). The PPF represents the various output combinations (bundles of products and services) that can be achieved using all resources and inputs available to society. Adoption of a technological innovation can be represented by changes in the PPF.

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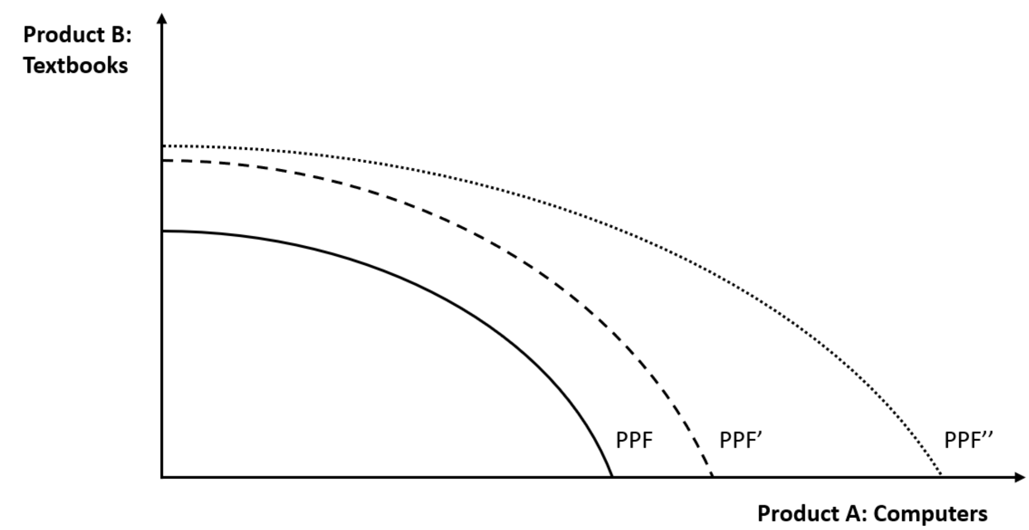
54 See, e.g., Perez, Carlota, "Harnessing the technological revolution," Financial Times Tech Tonic Podcast, November 2, 2016, available at https://www.ft.com/content/bf568bd3-e515-4784-8257-8a34eb2a93c4; The Deployment Age; The Death and Birth of Technological Revolutions.

55 Perez, Carlota (@CarlotaPrzPerez), "I respect your view. Theories belong to the public. But I see the present as the 1930s, the turning point…" [Twitter post], March 31, 2019, available at https://twitter.com/CarlotaPrzPerez/status/1112397085729533958?ref_src=twsrc%5Etfw. Perez also discusses this view in greater depth on the *Financial Times*' Tech Tonic podcast, stating that the present and the 1930s both exhibit(ed) "enormous technological potential which is not being used," with insufficient investment going into innovations because of insufficient demand—demand that is usually generated by "policies that are adequate for that particular revolution." For example, Perez discusses how suburbanization-favoring inventions and policies, such as the automobile and government welfare state, "tilt[ed] the playing field" to support home ownership and consumerism, which in turn supported and drove the revolution of mass production and relevant innovations. She discusses her view that "the most effective way of [tilting the playing field] today is tilting it towards 'green'"—not just investing in renewable energy, but in new lifestyles that are less energy and materials intensive. *See* Perez, Perez, Carlota, "Harnessing the technological revolution," *Financial Times* Tech Tonic Podcast, November 2, 2016, available at https://www.ft.com/content/bf568bd3-e515-4784-8257-8a34eb2a93c4; The Deployment Age; The Death and Birth of Technological Revolutions.

56 For a review of economic growth models, see Sharipov, Ilkhom, "Contemporary Economic Growth Models and Theories: A Literature Review," CES Working Papers, ISSN 2067-7693, Alexandru Ioan Cuza University of Iasi, Centre for European Studies, Iasi, Vol. 7, Iss. 3, pp. 759-773.

**Figure 7** illustrates the PPF and how it may change with technological innovation. Technological innovation can make inputs more productive, meaning that higher levels of output can be produced from the same level of inputs. In the figure, this may be reflected in a simple outward shift in the PPF from the solid line (PPF) to the dashed line (PPF'), indicating that all inputs become equally more productive. Alternatively, technological innovation may cause the comparative advantage between capital, labor, and other resources to change, affecting the way those inputs can be combined to produce goods and services. As the comparative advantage of different inputs changes, it may become easier to achieve higher levels of output of some goods than others. In the figure, this may be reflected in a change in both the level and shape of the PPF—for example, from the solid line (PPF) to the dotted line (PPF''), indicating that inputs used more heavily in the production of computers have become relatively more productive as a consequence of the technological innovation, and society therefore can now achieve output bundles with a relatively higher level of computers given a fixed set of resources.

**Figure 7. Production Possibilities Frontier**




### *2. Direct, indirect, and catalytic effects*

It is inherently difficult to determine exactly which industries will be affected by the metaverse and in what ways. However, we can think about the potential impacts of the metaverse in terms of direct effects, indirect effects, and catalytic effects.

*Direct effects.* We can be reasonably certain that the metaverse will first affect the industries that will create its infrastructure, including hardware, software, payment systems, and broadband providers. In particular, there will be significant changes in, for example, graphics processors, hardware used to interface with the metaverse (e.g., AR/VR), development of common software platforms that allow for movement through the metaverse, and blockchain technologies to establish ownership and payments. These "direct" economic impacts will accrue within industries involved in the development of infrastructure and ongoing provision of technology required to support the metaverse, similar to how Internet service providers reap direct economic benefits from the Internet.

*Indirect effects.* After the metaverse infrastructure is built out, industries that are likely to be affected early in the adoption process include: gaming, social networking, online retail, and education. These and other industries have potential to benefit from "indirect" economic impacts of the metaverse, such as through the creation of new jobs or products that are supported and made possible by the existence of the metaverse, similar to how the Internet "indirectly generates economic activity" in sectors of the economy outside of the direct provision of Internet services.

For example, gaming already accounts for the largest share of consumer spending on AR/VR, with over $3 billion in spending worldwide in 2020,[57] and according to the CEO of Microsoft Gaming, Phil Spencer, "video games in a way have been building what people are now defining as the metaverse for many, many years."[58] However, as illustrated by the use cases discussed in Section I, the potential of the metaverse is not limited to gaming. The metaverse is expected to drive significant incremental economic growth in remote work, health, education, and manufacturing. Advancement in technologies is already allowing manufacturing companies to create "digital twins" of manufacturing floors,[59] which can reduce the use of time, energy, and raw materials.[60] Manufacturing companies are also expected to use automation and simulation to design factory layouts and design components to be manufactured.[61]

*Catalytic effects.* Finally, similar to how computers, mobile phones, and the Internet have had wide-reaching effects on businesses and consumers that were impossible to predict with any precision, the metaverse could have "catalytic" effects on the economy, accelerating growth and productivity and creating impact that extends well beyond the businesses and industries directly involved with the infrastructure and early adoption of the metaverse, becoming integrated with traditional businesses, creating new jobs, and affecting consumers in new ways. We can see glimpses of this in novel uses of AR/VR in bias training, mental health treatment, and inclusive sports.

## C. Examples of breakthrough technologies

The economic theories of innovation we have discussed provide useful frameworks for understanding the diffusion and impact of prior technological innovations and thinking about the potential diffusion and impact of a new technological innovation like the metaverse.

Some of the most successful technological innovations of the 19$^{th}$ and 20$^{th}$ centuries include the steam engine, radio and television, personal computers, wireless Internet technology, and mobile technology, among others. We briefly discuss some of the impacts of these breakthrough technologies before turning in Section III to an in-depth analysis of mobile technology as a useful analogue—for now at least—for the metaverse.

57 Marketing Dive, "AR/VR spending will soar 79% to $18.8B next year, study predicts," December 2, 2019, available at https://www.marketingdive.com/news/arvr-spending-will-soar-79-to-188b-next-year-study-predicts/568224 ("Consumer spending on AR/VR next year will reach $7 billion, and the biggest categories of VR expenditures by consumers will be gaming at $3.3 billion and features at $1.4 billion as VR headsets become more affordable, IDC forecast.").

58 Thompson, Ben, "Microsoft Acquires Activision Blizzard, Notes on the Acquisition, An Interview With Microsoft Gaming CEO Phil Spencer," Stratechery, January 19, 2022, available at https://stratechery.com/2022/microsoft-acquires-activision-blizzard-notes-on-the-acquisition-an-interview-with-microsoft-gaming-ceo-phil-spencer/.

59 "A digital twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision-making." Armstrong, Maggie Mae, "Cheat sheet: What is Digital Twin?" IBM, December 4, 2020, available at https://www.ibm.com/blogs/internet-of-things/iot-cheat-sheet-digital-twin/.

60 Armstrong, Maggie Mae, "Cheat sheet: What is Digital Twin?" IBM, December 4, 2020, available at https://www.ibm.com/blogs/internet-of-things/iot-cheat-sheet-digital-twin/.

61 Rogers, David L., "A Sketch of the Industrial Metaverse," Exponential Industry, November 21, 2021, available at https://www.doclrogers.com/blog/2021-11-21-sketch-industrial-metaverse-nvidia-unity-meta-digital-twin-blockchain-extended-reality.

*Steam engines.* Steam engines signified one of the most consequential technological leaps in human history, powering the factories, trains, and ships that made the Industrial Revolution possible and serving as a launch pad for later innovations, such as internal combustion engines and jet turbines.[62] Economists have found that the Corliss steam engine, which represented a significant innovation in steam engine technology in the 19th century, "served as a catalyst for the industry's massive relocation into large urban centers, thus fueling agglomeration economies and further population growth" in the United States.[63] Using data from the 1870 census, the study found that the population of "counties with ten Corliss-driven establishments … grew at an annual rate 0.4 percent higher than counties with none."[64] A study focused on Britain also found that the peak impact of steam engines occurred after mid-19th century innovations in steam technology, with steam's total contribution to British labor productivity growth reaching 0.38% per year between 1850 and 1870.[65] However, put in context, recent estimates of the impact of the ICT industry on labor productivity, which range from 0.68% to 1.79% per year, suggest that steam engines' impact on economic growth in Britain was comparatively modest.[66]

*Radio and television.* The mid-20th century saw the invention and rise of radio and television broadcasting. By 1934, 60% of U.S. households had radios, while an additional 1.5 million units were installed in cars.[67] Sales of radio equipment in the United States reached $843 million by 1929,[68] and radio advertising reached $215.6 million by 1940.[69] However, radio was quickly supplanted by the emergence of television (TV). The adoption rate of televisions in the United States was remarkable, growing from 9% of households in 1950 to 86% of households just nine years later in 1959.[70] TV gave rise to popular sitcoms, Hollywood movies, political talk shows, educational programs, and reality shows, and it had immense economic, cultural, and political effects.[71]

*Personal computers.* In the second half of the 20th century, innovations in semiconductor technology enabled the widespread adoption of personal computers.[72] A body of academic literature from the late 1990s and early 2000s indicates that computers contributed significantly to economic growth over the past 50 years.[73] For example, Oliner

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62 The steam engine (external combustion engine) was invented by Thomas Savery in 1698, but its mass adoption didn't kick off until almost a century later when James Watt improved the technology. *See* Andrews, Evan, "11 Innovations That Changed History," History, February 18, 2021, available at https://www.history.com/news/11-innovations-that-changed-history.

63 Rosenberg, Nathan and Manuel Trajtenberg, "A General-Purpose Technology at Work: The Corliss Steam Engine in the Late-Nineteenth-Century United States." *The Journal of Economic History*, Vol. 64 (1), 2004, pp. 61–99.

64 Rosenberg, Nathan and Manuel Trajtenberg, "A General-Purpose Technology at Work: The Corliss Steam Engine in the Late-Nineteenth-Century United States." *The Journal of Economic History*, Vol. 64 (1), 2004, pp. 61–99.

65 Nicholas Crafts, "Steam as a General Purpose Technology: A Growth Accounting Perspective," *The Economic Journal*, Vol. 114, No. 495, April 2004, pp. 338–351

66 Nicholas Crafts, "Steam as a General Purpose Technology: A Growth Accounting Perspective," *The Economic Journal*, Vol. 114, No. 495, April 2004, pp. 338–351.

67 Scott, Carole E., "The History of the Radio Industry in the United States to 1940," Economic History, available at https://eh.net/encyclopedia/the-history-of-the-radio-industry-in-the-united-states-to-1940/.

68 Douglas, George H., "The Early Years of Radio Broadcasting," p. 75, Jefferson, NC: McFarland, 1987.

69 Sterling, Christopher H. and John M. Kittross, "Stay Tuned," p. 510, Belmont, CA: Wadsworth, 1978.

70 TV History. "Number of TV Households in America: 1950-1978," available at http://www.tvhistory.tv/Annual_TV_Households_50-78.JPG.

71 Stacker, Seth Berkman, "A Brief History of Television, By Decade," Culture at Newsweek, July 12, 2021, available at https://www.newsweek.com/brief-history-television-decade-1608854/.

72 Langlois, Richard, "Computers and Semiconductors. Technological Innovation and Economic Performance," 2002.

73 *See, e.g.,* Brynjolfsson, Erik and Lorin M. Hitt, "Computing Productivity: Firm-Level Evidence," *The Review of Economics and Statistics*, Vol. 85, No. 4, November 2003, available at https://repository.upenn.edu/cgi/viewcontent.cgi?article=1040&context=oid_papers, p. 793 ("[…] the productivity and output contributions associated with computerization are up to 5 times greater over long periods […]"); Oliner, Stephen D. and Daniel E. Sichel, "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?" *Journal of Economic Perspectives*, Vol. 14, No. 4, Fall 2000, p. 21, available at https://pubs.aeaweb.org/doi/pdfplus/10.1257/jep.14.4.3 (The growth of labor productivity rebounded in the second half of the 1990s […] we estimate that information technology accounted for about two-thirds of the step-up in labor productivity growth between the first and second halves of the decade."); Brynjolfsson, Erik and Lorin Hitt, "Computers

and Sichel (2000) found that information technology (computer hardware, software, and communication equipment) accounted for 68 percent (0.71 percentage points) of the acceleration in labor productivity during the 1990s, with the "rapidly improving technology for producing computers" contributing 0.26 percentage points to this acceleration.[74] Jorgenson and Vu (2005) found that, over the 1995-2003 period, information technology capital accounted for about 15 percent (0.53 percentage points) of world GDP growth.[75]

*Internet.* Further advancements in semiconductor technology, in parallel with other advances, enabled widespread adoption of the Internet beginning at the end of the 20th century.[76] A number of studies have estimated the economic impacts associated with the Internet, establishing positive relationships between Internet access and trade, employment, and productivity. The Internet's share of total U.S. GDP is estimated to have ranged from about 2% to 6% between 1998 and 2017.[77,78] Furthermore, one study estimates that 34% of total U.S. export value (a component of GDP) was from "digitally-deliverable services" in 2011.[79] The Internet allows more countries to participate in the global value chain and learn from the global productivity frontier. Based on a sample of 56 countries, Freund and Weinhold (2004) find that a 10 percentage point increase in the growth of web hosts in a

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and Economic Growth: Firm-Level Evidence," *MIT Sloan Working Papers*, August 1994, p. 23, available at https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.698.2765&rep=rep1&type=pdf ("We found [that computer capital] and [information system labor] made large and statistically significant contributions to the output of the firms in our sample."); Jorgenson, Dale W. and Kevin J. Stiroh, "Productivity Growth: Current Recovery and Longer-Term Trends," *American Economic Review*, Vol. 89, No. 2, May 1999, p. 109, available at https://www.aeaweb.org/articles?id=10.1257/aer.89.2.109 ("This substitution [of IT equipment for other forms of capital and labor] generates substantial returns for the economic agents who undertake IT investments […]").

74 Oliner and Sichel 2000, pp. 18-19 ("[W]e attribute 0.45 percentage point of the pickup to the growing use of information technology capital throughout the nonfarm business sector. The rapidly improving technology for producing computers […] contributed another 0.26 percentage point to the acceleration.").

75 Jorgenson, Dale W. and Khuong Vu, "Information Technology and the World Economy," *Proceedings*, Federal Reserve Bank of San Francisco, 2005, p. 21, available at https://www.frbsf.org/economic-research/files/6_ITAndWorldEconomy.pdf. *See also* Harris et al., "Impact of Computing on the World Economy: A Position Paper," *Proceedings of the ISCA 24th International Conference on Computers and Their Applications - CATA 2009, April 8-10*, 2009, New Orleans, Louisiana, pp. 271-272, available at https://www.cse.unr.edu/~fredh/papers/conf/074-iocotweapp/paper.pdf ("According to [...] Jorgenson and Vu, [… t]he contribution of IT capital deployment [to world GDP growth] almost doubled from 0.27% to 0.53% during these periods [1989-1995 and 1995-2003, respectively].").

76 Heaven, Douglas, "The humble mineral that transformed the world," Made On Earth, BBC, available at https://www.bbc.com/future/bespoke/made-on-earth/how-the-chip-changed-everything/.

77 The earliest study estimated that approximately $300 billion in revenue and 1.2 million jobs could be directly attributed to the Internet in 1998. The revenue estimate includes sales of business-to-business goods and services, which are not included in GDP; however, as a point of reference, the $300 billion in revenue would have amounted to about 3 to 4 percent of GDP in 1998. *See* The Internet Economy Indicators, "Q&A on the Internet Economy," available at http://anciensdefcr.eu/histoire/ASE_web_janv2000/alertes/actualites/economie_internet/web_etude/qa.html. *See also* DePrince Jr., Albert E. and William F. Ford, "A primer on internet economics: macro and micro impact of the internet on the economy," *Business Economics*, Vol. 34, No. 4, October 1999, available at https://link.gale.com/apps/doc/A56973857/AONE?u=mlin_oweb&sid=googleScholar&xid=44507bb8.

78 A series of recent studies commissioned by the Interactive Advertising Bureau and conducted by researchers at Harvard Business School measured the impact of the Internet in terms of total wages for Internet-related jobs and jobs supported by the Internet elsewhere in the economy. These studies have found that the Internet's contribution to U.S. GDP increased over time: $300 billion (2.1% of GDP) in 2008; $530 billion (3.7% of GDP) in 2011; and $1,121 billion (6.0% of GDP) in 2016. *See* Quelch, John, "Quantifying the Economic Impact of the Internet," *Harvard Business School*, August 17, 2009, available at https://hbswk.hbs.edu/item/quantifying-the-economic-impact-of-the-internet ("The Internet employs 1.2 million people directly […] Each Internet job supports approximately 1.54 additional jobs elsewhere in the economy, for a total of 3.05 million, or roughly 2 percent, of employed Americans. The dollar value of their wages is about $300 billion, or around 2 percent of U.S. GDP."); Deighton, John and Leora D. Kornfeld, "Economic Value of the Advertising-Supported Internet Ecosystem," *Interactive Advertising Bureau,* September 2012, p. 81, available at https://www.hbs.edu/ris/Publication%20Files/EVASIE_2012_September_9d78c1c2-51be-4431-9a11-e19e26f71b80.pdf ("By this method, the advertising-supported Internet ecosystem contributes about $530 billion to the U.S. GDP in 2011."); Deighton, John, Leora Kornfeld, and Marlon Gerra, "Economic Value of the Advertising-Supported Internet Ecosystem," *Interactive Advertising Bureau*, January 2017, p. 7, available at https://www.iab.com/wp-content/uploads/2017/03/Economic-Value-Study-2017-FINAL2.pdf ("[T]he advertising-supported internet ecosystem contributes about $1,121 billion to the U.S. GDP in 2016.").

79 Digitally deliverable services include business, professional and technical services, royalties and license fees, insurance, finance, and telecommunications. *See* Nicholson, Jessica R. and Ryan Noonan, "Digital Economy and Cross-Border Trade: The Value of Digitally-Deliverable Services*," U.S. Department of Commerce Economics and Statistics Administration Issue Brief 01-14*, January 2014, p. 2.

country leads to a 0.2 percentage point increase in goods export growth by cutting the fixed costs of market entry.[80] Focusing on countries in Africa, Hjort and Poulsen (2019) find that submarine cable arrival (signaling the availability of fast Internet) increased the employment rate by 4.6 percentage points (6.9%) and 7.7 percentage points (13.2%) in two groups of African countries—and that increased firm entry, productivity, and exporting contributed to higher net job creation in those African countries.[81] With data from the EU, Brazil, China, Vietnam, Indonesia, Korea, Russia, and India, Van der Marel et al. (2015) estimate that barriers that regulate data flows dampen total factor productivity by almost 3.9%.[82]

In summary, existing academic literature and industry studies indicate that many breakthrough technologies have had substantial economic impacts on countries all around the world. In the next section, we turn to existing research on mobile technology to contextualize our decision to focus on mobile technology to help quantify the economic potential of the metaverse.

# III. Mobile Technology

In this section, we discuss our reasoning for focusing on mobile technology as an analogue for the metaverse, and we review existing research that has measured the direct, indirect, and catalytic effects that mobile technology has had on global and local economies.

## A. Focus on mobile technology

We define mobile technology for the purpose of our analysis as mobile devices enabled with Internet access—such as smartphones and tablets—and the infrastructure and related ecosystems that support the use of mobile devices.[83] While mobile devices can be viewed more broadly to include early cellular phone models and handheld devices, we focus on the revolutionary changes brought about by combining such devices with access to the Internet and data, as discussed further below. **Figure 8** provides illustrative examples to show the evolution in the design of mobile phones from the first Motorola cell phone introduced in 1983 to the first iPhone introduced in 2007.

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80 Freund, Caroline, and Diana Weinhold, "The Effect of the Internet on International Trade," *Journal of International Economics*, Vol. 62, 2004, p. 184.

81 Hjort, Jonas, and Jonas Poulsen, "The Arrival of Fast Internet and Employment in Africa," *American Economic Review*, Vol. 109(3), March 2019, p. 1050.

82 van der Marel, Erik, Matthias Bauer, Hosuk Lee-Makiyama, and Bert Verschelde, "A Methodology to Estimate the Costs of Data Regulations," *International Economics* 146, December 2015, p. 14.

83 As described further below, in our analysis we measure mobile technology adoption using the variable "mobile broadband adoption per 100 people" from the International Telecommunications (ITU). According to the ITU, "Active mobile-broadband subscriptions refers to the sum of active handset-based and computer-based (USB/dongles) mobile-broadband subscriptions to the public Internet. It covers actual subscribers, not potential subscribers, even though the latter may have broadband-enabled handsets. Subscriptions must include a recurring subscription fee or pass a usage requirement – users must have accessed the Internet in the last three months. It includes subscriptions to mobile-broadband networks that provide download speeds of at least 256 kbit/s (e.g. WCDMA, HSPA, CDMA2000 1x EV-DO, WiMAX IEEE 802.16e and LTE), and excludes subscriptions that only have access to GPRS, EDGE and CDMA 1xRTT." *See* ITU, "WTI Indicators with Definitions," p. 12, available at https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Documents/Events/2017/Aug-aspstat2017/WTI_Indicators_with_Definitions_14Aug2017_final.pdf.

**Figure 8. Evolution of Mobile Phones, 1983–2007**


While we could use any breakthrough technological innovation for our analysis, we view mobile technology as particularly well suited for two reasons.

First, the way mobile technology evolved to change the way we use the Internet is reminiscent of the path the metaverse appears to be poised to follow. When the iPhone was introduced in 2007, it was a combination of technologies that already existed, including a mobile phone, the Internet, MP3 player, and camera, with a proposition that it would improve user experience.[84] Although these technologies each already existed on their own, putting them together in a single device fundamentally altered how users connect with the Internet by overcoming the limitations of geography. With access to the Internet at their fingertips, users were no longer tethered to the physical location of a desktop computer, and all types of experiments of new potential use cases for the Internet eventually arose through the innovations of creators. Consequently, some of these experiments became viable solutions for people, such as ordering a taxi and automatically paying for the ride with your credit card information (Uber), or rural farmers and agricultural vendors engaging in entrepreneurship and selling produce via smartphones and livestreaming platforms.[85] The convenience and expectation that consumers would have continual access to fast cellular networks fueled investments in smartphone handsets and the development of mobile applications, which in turn transformed the way people work, find entertainment, and connect.[86]

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84 Miller, Chance, "15 years of iPhone: Rewatch the original Steve Jobs keynote announcing the iPhone," 9To5Mac, January 9, 2022, available at https://9to5mac.com/2022/01/09/steve-jobs-original-iphone-announcement-15-years/.

85 David S. Evans, and Howard H. Chang, and Steven Joyce, "What Caused the Smartphone Revolution?" September 17, 2019, p. 12 ("Smartphone Revolution"); Selina Xu, "Livestreaming Farmers Earn Millions From Fruit on China's TikTok," Bloomberg Wealth, July 6, 2021, available at https://www.bloomberg.com/news/articles/2021-07-07/livestreaming-farmers-earn-millions-from-fruit-on-china-s-tiktok.

86 Smartphone Revolution, p. 15.

Existing conceptions of the metaverse have a similar flavor of combining existing technologies—in this case, AR/VR, mixed and extended realities, videoconferencing, multi-player gaming—and turning them into something new that fundamentally transforms how we connect with each other and further breaks down location barriers by enabling seamless and immersive experiences without the need to be physically present in one location.[87] The wide range of expected applications for the metaverse is also similar to that of mobile technology, including in the communications, entertainment, education, healthcare, manufacturing, and retail sectors.

Second, mobile technology is a relatively recent—but not too recent—technological innovation, and data on its adoption are readily available for countries all around the world. Data on older technologies are likely to be more sparse, while newer technologies such as AR and VR are too recent to have completed the full evolution of their adoption and direct, indirect, and catalytic effects on economies. Mobile technology fills the sweet spot as being both rich with data and having similar value propositions as envisioned for the metaverse.

## B. Literature on the economic impacts of mobile technology

A number of academic and industry studies have measured the impact of mobile technology on economic output (typically measured in terms of gross domestic product, or GDP) and other economic indicators in both developed and developing countries. As discussed in Section II, technological innovation can drive new growth in output, or it can displace output from other sectors of the economy. Depending on the sector or region, this can have positive or negative effects on output, employment, prices, and other economic indicators. In this section, we review existing empirical research on the economic impact of mobile technology. Overall, while different studies define and measure mobile technology in different ways, the existing research indicates that in a wide range of contexts and across various definitions and measures, mobile technology has had a substantial and beneficial impact on global and local economies.

First, mobile technology is associated with a large share of global GDP. A series of studies conducted by the industry organization GSMA found that the "mobile economy" contributed approximately $2.4 trillion (3.6%) to global GDP in 2013, $3.9 trillion (4.6%) to global GDP in 2018, and $4.4 trillion (5.1%) to global GDP in 2020.[88] These estimates include direct contributions (e.g., mobile operators and related infrastructure), indirect contributions, and productivity contributions, with productivity accounting for the largest share of GDP—for

87 The Global Herald, "Metaverse: How Roblox-Inspired Companies Are Bringing the Internet to Life," August 11, 2021, available at https://theglobalherald.com/news/metaverse-how-roblox-inspired-companies-are-bringing-the-internet-to-life/ ("Cutting-edge metaverse applications are still at the conceptual stage. If they do become reality, virtual meetings and shopping online would feel like real-life activities, with digital copies of almost everything that also reflect real-world changes in real time through advanced 3D image capturing.").

88 GSMA includes direct contributions from mobile operators and the "rest of [the] mobile ecosystem" as well as "[a]dditional indirect and productivity benefits" in its estimate of contribution to GDP. Similarly, GSMA includes direct employment by mobile operators, distributors and retailers, and the rest of the mobile ecosystem, as well as indirect employment by "adjacent industries" in its estimate of contribution to employment. *See* "How the Smartphone has Impacted Economic Development," *The University of Scranton*, available at https://elearning.scranton.edu/resource/business-leadership/how-the-smartphone-has-impacted-economic-development ("According to a major report conducted by GSMA, the mobile economy contributed an estimated $2.4 trillion to the international economy in 2013, representing about 3.6% of global gross domestic product."); GSMA 2019, p. 4 ("In 2018, mobile technologies and services generated $3.9 trillion of economic value (4.6% of GDP) globally […]"); GSMA, "The Mobile Economy," 2021, ("GSMA 2021"), p. 38, available at https://www.gsma.com/mobileeconomy/wp-content/uploads/2021/07/GSMA_MobileEconomy2021_3.pdf ("In 2020, mobile technologies and services generated 5.1% of global GDP, a contribution that amounted to almost $4.4 trillion of economic value added.").

example, $2.9 trillion (3.4%) in 2020.[89] Moreover, the study found that in 2020, the global mobile industry directly employed about 12 million people and indirectly employed another 13 million people in adjacent industries.[90]

Second, studies have found that mobile technology has contributed to GDP growth. Using data on both developed and developing countries, a 2012 Deloitte study found that a 10% substitution from 2G to 3G penetration was associated with a 0.15 percentage point increase in the GDP per capita growth rate globally. Furthermore, a doubling of mobile data usage was associated with a 0.5 percentage point increase in the GDP per capita growth rate.[91] While these empirical estimates are based on both developed and developing countries, Aker and Mbiti (2010) identify five potential mechanisms through which mobile technology adoption can impact growth in undeveloped economies, some of which may also apply to developed countries. The mechanisms include: (1) improving access to information and reducing search costs, (2) improving firms' productive efficiency, (3) creating new jobs, (4) reducing households' risk by improving communication within their social network, and (5) delivering financial, agriculture, health, and education services via mobile apps and platforms.[92]

Third, a handful of studies have focused on measuring the impact of mobile technology specifically in developing countries, exploring a range of different economic indicators. Waverman et al. (2005) find that a 10% increase in mobile penetration was associated with a 0.6% increase in GDP per capita growth rate in developing countries, which is up to two times larger than the impact in developed countries.[93] This finding could be driven by the "leap frogging" opportunities for many poor countries resulting from mobile phones being substitutes for fixed lines as the main communication networks, and therefore enabling such countries to "supplant the information-gathering role of fixed-line systems.[94] Andrianaivo and Kpodar (2011) study mobile technology's interaction with financial

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89 The GSMA reports do not elaborate on what is included in "indirect" and "productivity" contributions.

90 GSMA 2021, p. 39.

91 The study also found that a 10% increase in mobile penetration (the number of mobile phone subscribers per 100 population, which includes subscribers with basic cellular phone plans that do not have broadband Internet access) increases total factor productivity in the long run by 4.2 percentage points. *See* Deloitte, "What is the Impact of Mobile Telephony on Economic Growth? A Report for the GSM Association," November 2012, available at https://www.gsma.com/mobilefordevelopment/resources/what-is-the-impact-of-mobile-telephony-on-economic-growth/, p. 2 ("For a given level of total mobile penetration, a 10 per cent substitution from 2G to 3G penetration increases GDP per capita growth by 0.15 percentage points […] A doubling of mobile data use leads to an increase in the GDP per capita growth rate of 0.5 percentage points […] A 10 per cent increase in mobile penetration increases Total Factor Productivity in the long run by 4.2 percentage points."). *See also* Recon Analytics and ctia, "The 4G Decade: Quantifying the Benefits," July 2020, ("Recon and ctia The 4G Decade"), available at http://reconanalytics.com/2020/07/the-4g-decade-quantifying-the-benefits/, p. 4 ("Thanks to 4G, U.S. GDP grew $248.7B more than projected").

92 Here, "mobile technology" refers to mobile phones. *See* Aker, Jenny, and Isaac M. Mbiti, "Mobile Phones and Economic Development in Africa," *Journal of Economic Perspectives*, Vol. 24(3), 2010, pp. 213–214.

93 Here, "mobile penetration" pertains to mobile phone penetration. *See* Waverman, L., M. Meschi and M. Fuss, "The Impact of Telecoms on Economic Growth in Developing Countries," in Africa: The Impact of Mobile Phones, Vodafone Policy Paper Series, No. 2, March 2005. *See also* Roller, Lars-Hendrik, and Leonard Waverman, "Telecommunications Infrastructure and Economic Development: A Simultaneous Approach," The American Economic Review, vol. 91 (4), September 2001. Roller and Waverman (2001) found a statistically significant positive causal link between landline and telex penetration and GDP growth for OECD countries, where a 1% increase in penetration increases economic growth by 0.045%. Furthermore, they found that a critical mass of 40% penetration leads to increasing returns on telecom investments.

94 Technology leapfrogging refers to adopting the latest technology in a setting where the previous generation of the technology was not present. *See, e.g.,* Fong, Michelle Wye Leng (2009) Technology leapfrogging for developing countries. In: Encyclopedia of Information Science and Technology. Khosrow-Pour, Mehdi, ed. Information Science Reference, Hershey, Pa, USA, pp. 3707-3713; Waverman, L., M. Meschi and M. Fuss, "The Impact of Telecoms on Economic Growth in Developing Countries," in Africa: The Impact of Mobile Phones, Vodafone Policy Paper Series, No. 2, March 2005, p. 2 ("We find that mobile telephony has a positive and significant impact on economic growth, and this impact may be twice as large in developing countries compared to developed countries. This result concurs with intuition. Developed economies by and large had fully articulated fixed-line networks in 1996. Even so, the addition of mobile networks had significant value-added in the developed world: the value-added of mobility and the inclusion of disenfranchised consumers through pay-as-you-go plans unavailable for fixed lines. In developing countries, we find that the growth dividend is far larger because here mobile phones provide, by and large, the main communications networks; hence they supplant the information-gathering role of fixed-line systems.").

inclusion, and estimate that in African countries where mobile financial services exist, mobile penetration further enhances the contribution of financial inclusion to economic growth by 7.42% relative to countries where these services are not yet deployed.[95,96] Lastly, within-country studies show that breaking down geographic barriers to information and communication reduces price dispersion of agricultural and fishing goods and increases welfare.[97] For example, in Kerala, India, greater mobile coverage that made mobile service available in areas of the sea where most fishing occurred allowed fishermen to coordinate with traders and take advantage of spatial arbitrage opportunities that increased profits and consumer surplus by 8% and 6%, respectively, while decreasing consumer prices by 4%.[98] In Niger, mobile phones allowed grain traders to obtain price information without having to physically travel to a market (as was traditionally the case), thereby reducing search costs and time and increasing search breadth, leading to reduced price dispersion across markets.[99]

Finally, while many studies indicate that mobile technology has had a net positive impact on both developed and developing economies, the literature also raises some potential risks and tradeoffs of mobile technology adoption. For example, Kentaro Toyama, a computer scientist and international development researcher, explains that in the context of development, “technology tends to amplify existing inequalities” and “helps the rich get proportionately richer, thus widening, not narrowing, the gaps between rich and poor.”[100] Toyama identifies three mechanisms through which technology can increase inequality: differential access, differential capacity (e.g., disparities in skill), and differential motivation.[101] Wych, Simiyu, and Othieno (2016) found that the dissonance caused by differential capacity and differential motivation among rural Kenyan women’s mobile phone usage resulted in the amplification of existing inequalities. The design interface of Safaricom, Kenya’s largest network provider, confused and complicated rural Kenyan women’s ability to use their handsets, sometimes leading them to lose money to the

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95 Mobile financial services (MFS) refers to branchless banking services offered through mobile network operators (MNO). The user would open an account or e-wallet with the MNO, and give cash to the MNO in exchange for an electronic record of value on a virtual account kept through the MNO. In addition to the basic deposit and withdrawal services, users can also electronic money to other users via text messages The countries and MFS in the study include Zambia (CELPAY), South Africa (WIZZIT and MTN Mobile Money), and Kenya (M-PESA).

96 Here, “mobile technology” refers to mobile phones and “mobile penetration” refers to mobile phone penetration. *See* Andrianaivo, Mihasonirina, and Kangni Kpodar, “ICT, Financial Inclusion, and Growth: Evidence from African Countries,” IMF Working Paper No. 11/73, April 2011.

97 *See e.g.*, Robert Jensen, “The Digital Provide: Information (Technology), Market Performance, and Welfare in the South Indian Fisheries Sector,” The Quarterly Journal of Economics, vol. 122 (3), 2007; Jenny C. Aker, “Information from Markets Near and Far: Mobile Phones and Agricultural Markets in Niger,” *American Economic Journal: Applied Economics*, Vol. 2(3), July 2010.

98 Here, “mobile coverage” pertains to mobile phones. *See* Jensen, Robert, “The Digital Provide: Information (Technology), Market Performance, and Welfare in the South Indian Fisheries Sector,” *The Quarterly Journal of Economics 122(3),* August 2007, pp. 879-924, available at https://web.stanford.edu/class/comm1a/readings/jensen-digital-divide.pdf, p. 883 (“[F]ishermen’s profits increased on average by 8 percent while the consumer price declined by 4 percent and consumer surplus in sardine consumption increased by 6 percent […]”).

99 Aker, Jenny C., “Information from Markets Near and Far: Mobile Phones and Agricultural Markets in Niger,” *American Economic Journal: Applied Economics 2,* July 2010, pp. 46-59, pp. 46-47 (“As grain traders have traditionally traveled to markets to obtain price information for agricultural goods, mobile phones should have reduced their search costs, allowing them to search over a larger number of markets more quickly. This effect was supported by the grain traders themselves, one of whom stated, ‘[With a mobile phone], I know the price for US $2, rather than traveling (to the market), which costs US $20.’”); pp. 57-58 (“The introduction of mobile phones is associated with a 10 to 16 percent reduction in price dispersion across [agricultural] markets […] the primary mechanism through which mobile phones affect market-level outcomes is a reduction in search costs, as grain traders operating in mobile phone markets change their search and marketing behavior as compared to their non-mobile phone counterparts.”).

100 Kentaro Toyama, “Technology as Amplifier in International Development,” iConference '11: Proceedings of the 2011 iConference, 2011.

101 Differential access refers to inequalities among consumers that affect their access to technologies; differential capacity refers to how “disparities among people, such as better education, refined social skills, and influential connections all translate to a greater ability for the better-off to use technology for their own purposes”; and differential motivation refers to “what people want to do with the technology they have access to.” *See* Kentaro Toyama, “Technology as Amplifier in International Development,” iConference '11: Proceedings of the 2011 iConference, 2011.

country's for-profit network provider rather than engaging in income-generating activities.[102] An implication of this literature is that technology alone cannot fix or address disparities in access, capacity, and motivation—rather, it tends to amplify existing inequalities in these dimensions. The research indicates that technological innovations are most likely to be successful in developing economies if they "amplify already successful development efforts or positively inclined intent."[103]

Overall, the existing research on the economic impacts of mobile technology indicates that mobile technology has had many substantial impacts on global and local economies—in terms of GDP, jobs and employment, productivity, and other dimensions that contribute to consumer welfare. An implication is that if the metaverse were to be adopted and diffused in a similar way as mobile technology, it would have the potential to have similarly wide-reaching economic impacts.

# IV. Empirical Analysis of the Economic Impact of Mobile Technology

In this section, we build off the existing literature and accepted econometric methods to develop an empirical approach to estimate the impact of mobile technology adoption on GDP growth. We then use the results as a benchmark for calculating the potential economic impact of the metaverse on GDP growth in Section V.

Our goal is to utilize a parsimonious approach that is simple and flexible enough to be applied broadly across different regions and that uses data that are readily available for most, if not all, countries around the world. At the same time, we develop a rigorous approach grounded in methods that have been widely applied in existing research, and thus can be replicated or leveraged for other similar efforts.

Broadly, studies of economic impact of new technologies take one of two methodological approaches. One group of studies uses macro-level panel data such as from the International Monetary Fund or the World Bank, leveraging variation across many different countries and over time to estimate the impact of a technology on GDP growth. These studies typically regress the growth rate of GDP per capita on a measure of adoption of the technology and a number of other economic indicators.[104] To address potential endogeneity concerns, these studies often use the lags of the endogenous variables as instruments and estimate the parameters of the model

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102 For example, some respondents were subscribed to premium services without their active knowledge and were unaware of how to unsubscribe from these services because of the cumbersome process to do so. The "process [to unsubscribe] involves entering a short code, navigating five different menus, answering queries by inputting a number, scrolling to the bottom of menus, translating unfamiliar terms (i.e., "Selfcare" and "International Voice Bundles"), and selecting an option that provides no feedback to confirm that users have actually unsubscribed." *See* Susan Wych, Nightingale Simiyu, and Martha E. Othieno, "Mobile Phones as Amplifiers of Social Inequality among Rural Kenyan Women," *ACM Transactions on Computer-Human Interaction, Volume 23, Issue 3*, 2016 ("Our analysis suggests that [Safaricom's] design at the very least contributes to confusing and complicating our rural Kenyan respondents' abilities to use their handsets, and at worst, results in them losing money to the country's for-profit network provider.").

103 Kentaro Toyama, "Technology as Amplifier in International Development," iConference '11: Proceedings of the 2011 iConference, 2011.

104 *See, e.g.,* Deloitte, "What is the impact of mobile telephony on economic growth? A Report for the GSM Association," November 2012; Ulku, Hulya, "R&D, Innovation, and Economic Growth: An Empirical Analysis," *IMF Working Paper,* September 2004; Andrianaivo, Mihasonirina and K. Kpodar, "ICT, Financial Inclusion, and Growth: Evidence from African Countries," *IMF Working Paper,* April 2011; Lee, Sang H., J. Levendis, and L. Gutierrez, "Telecommunications and Economic Growth: An Empirical Analysis of Sub-Saharan Africa," *Applied Economics 44(4),* October 2009; Roller, Lars-Hendrik and L. Waverman, "Telecommunications Infrastructure and Economic Development: A Simultaneous Approach," *The American Economic Review 91(4),* September 2001, pp. 909-923; Waverman, L., M. Meschi and M. Fuss, "The Impact of Telecoms on Economic Growth in Developing Countries," in Africa: The Impact of Mobile Phones, *Vodafone Policy Paper Series*, No. 2, March 2005.

with generalized method of moments. A second group of studies uses micro-level data from a single country, leveraging variation within a country—such as staggered timing of mobile enrollment or internet cable arrival (enabling fast internet)—to identify the impact of the technology on outcomes like consumer welfare, employment, and price dispersion using a quasi-experimental design.[105] While the latter studies can take advantage of unique identification strategies, their results may not be generalizable to other countries or settings.

Given our focus on modeling the economic impact of mobile technology for a broad range of countries and regions, we take the first approach, using the Arellano-Bond generalized method of moments (GMM) estimator.[106] We view these estimates as a useful first-order approximation of the relationship between a breakthrough technological innovation and economic growth, which helps ground our estimate of the metaverse's potential economic impact.

## A. Model

For our baseline model, we follow Waverman, Meschi, and Fuss (2005) and Andrianaivo and Kpodar (2011) to study the relationship between GDP per capita growth and mobile broadband adoption. The equation is as follows:

$$\ln\left(GDPpc_{i,t}\right) - \ln\left(GDPpc_{i,t-1}\right) = \alpha \ln\left(GDPpc_{i,t-1}\right) + \beta \ln\left(mobile\ BB_{i,t}\right) + X'_{i,t}\Gamma + \nu_{i,t}$$

$$\nu_{i,t} = \eta_i + \epsilon_{i,t}\ ,$$

where $GDPpc_{i,t}$ is GDP per capita in country $i$ and year $t$, and $mobile\ BB_{i,t}$ is the number of mobile broadband subscriptions per 100 people in country $i$ and year $t$. Following the economic growth literature, we control for other country-level variables that can impact GDP growth.[107] $X_{i,t}$ includes the following control variables: the number of fixed broadband subscriptions per 100 people, the number of patent applications per capita, secondary school enrollment, the fertility rate, government expenditure as a percent of GDP, and gross capital formation as a percent of GDP.[108] Finally, $\eta_i$ is a country fixed effect, and $\epsilon_{i,t}$ are idiosyncratic errors. The coefficient of interest is $\beta$.

Rearranging the lag of GDP per capita, we can estimate the following equation using ordinary least squares (OLS):

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105 *See, e.g.,* Jensen, Robert, "The Digital Provide: Information (Technology), Market Performance, and Welfare in the South Indian Fisheries Sector," *The Quarterly Journal of Economics 122(3),* August 2007; Aker, Jenny C., "Information from Markets Near and Far: Mobile Phones and Agricultural Markets in Niger," *American Economic Journal: Applied Economics 2,* July 2010, pp. 46-59; Hjort, Jonas, and Jonas Poulsen, "The Arrival of Fast Internet and Employment in Africa," *American Economic Review*, Vol. 109(3), March 2019; Jack, William, and Tavneet Suri, "Risk Sharing and Transactions Costs: Evidence from Kenya's Mobile Money Revolution," *American Economic Review*, Vol. 104(1), January 2014, pp. 183 - 223.

106 Arellano, Manuel, and Stephen Bond, "Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations," *Review of Economic Studies*, Vol. 53, 1991.

107 *See, e.g.,* Barro, Robert J., "Economic Growth in a Cross Section of Countries," *The Quarterly Journal of Economics 106(2*), May 1991, pp. 407-443; Waverman, Meschi, and Fuss (2005); Andrianaivo and Kpodar (2011).

108 Secondary school enrollment is the ratio of total secondary school enrollment (regardless of age) to the population of secondary school age group. Fertility rate is the average number of children that would be born to a woman over her lifetime that would survive to at least 5-years old. Gross capital formation is the outlays on additions to the fixed assets of the economy plus net changes in the level of inventories. *See* The World Bank, "DataBank: World Development Indicators," available at https://databank.worldbank.org/source/world-development-indicators.

$$\ln(GDPpc_{i,t}) = \gamma \ln(GDPpc_{i,t-1}) + \beta \ln(mobile\ BB_{i,t}) + X'_{i,t}\Gamma + \nu_{it} \quad (1)$$

$$\nu_{it} = \eta_i + \epsilon_{i,t} ,$$

where $\gamma = 1 + \alpha$.

The model shown in equation 1 could suffer from endogeneity because higher GDP per capita can increase demand for mobile broadband through income effects. Another source of endogeneity is the correlation between $GDPpc_{i,t-1}$ and the error term $\nu_{it}$. To address these endogeneity issues, we follow Arellano and Bond (1991) in estimating the model using the GMM estimator and time-specific instrumental variables, where the population moment $E(Z'\Delta\epsilon) = 0$ requires that the instruments are uncorrelated with the differenced errors. We perform a set of robustness checks to test for the validity of the instruments.

We estimate the first-difference specification using a two-stage GMM estimator, implemented with the xtabond Stata command. We assume the following logged variables are endogenous: the number of mobile broadband subscriptions per 100 people, the number of fixed broadband subscriptions per 100 people, and the number of patent applications per capita. To limit the number of instruments, we only use the second lags of these three variables, and the second and third lags of log GDP per capita as instruments. We assume the remaining first-differenced variables (primary and secondary enrollment, fertility, government expenditure, and gross capital formation) are exogenous and are their own instruments. We report Windmeijer-corrected robust standard errors, which provide finite sample correction for the variance of two-step GMM estimators.

## B. Data

Our main data source is the World Bank's World Development Indicators database (WDI). According to the World Bank, WDI is the organization's primary collection of development indicators, "compiled from officially recognized international sources" and "presents the most current and accurate global development data available."[109] WDI contains panel data covering up to 266 individual countries and territories from 1960 to 2019, depending on the indicator(s) selected from over 1,400 available indicators.[110] The data can also be aggregated to geographical

109 The World Bank, "DataBank," available at https://databank.worldbank.org/home.aspx ("World Development Indicators (WDI) is the primary World Bank collection of development indicators, compiled from officially recognized international sources. It presents the most current and accurate global development data available, and includes national, regional and global estimates.").

110 WDI data are collected from various sources, including other international organizations (e.g., UNESCO, ITU, WIPO) and national accounts data files. Regardless of a specific indicator's data source, the data available in WDI are directly impacted by the upstream sources. Gaps in data coverage may be due to administrative reasons—such as the year in which a dataset or indicator was introduced in a country, changes to indicator definitions or data collection methodology, or an incomplete or delayed submission; gaps may also be due to quality or statistical reasons—such as low distribution frequency of a survey, political instability or lack of statistical capacity, or other data quality concerns. For example, WDI includes data on gross school enrollment ratios from UNESCO; if there are gaps in UNESCO's data on school enrollment, potentially due to any combination of the causes mentioned above, these gaps would be reflected in the WDI data as well. In addition, high-income countries that do not borrow from the World Bank are not obligated to report data on certain indicators related to debt and aid, among others, which may contribute to gaps in data coverage for these indicators. *See* The World Bank, "Data: Why are some data not available?" available at https://datahelpdesk.worldbank.org/knowledgebase/articles/191133-why-are-some-data-not-available; The World Bank, "DataBank: World Development Indicators," available at https://databank.worldbank.org/source/world-development-indicators; The World Bank, "Data: Why is there missing data for high-income countries?" available at https://datahelpdesk.worldbank.org/knowledgebase/articles/198559; UNESCO, "UIS Education Data Release: September 2019," available at http://uis.unesco.org/sites/default/files/documents/ip59-uis-education-data-release-september-2019.pdf; UNESCO, "Background Information on Education Statistics in the UIS Dataset," September 2021, available at http://data.uis.unesco.org/ModalHelp/OECD/background-information-education-statistics-uis-database-en.pdf.

regions, international economic/financial organizations, and socioeconomic groups of countries.[111] The variables we use from WDI are GDP per capita in constant 2015 USD, fixed broadband subscriptions per 100 people, resident and non-resident patent applications per capita, secondary school gross enrollment ratio, total fertility rate, under-5 mortality rate per 1,000 live births, general government final consumption expenditure as a percent of GDP, and gross capital formation as a percent of GDP.

We supplement the data from WDI with data from the World Bank's complete DataBank, which includes additional databases focused on governance and regulation, development, jobs and labor, infrastructure, remittance, and debt. The variable we use from the DataBank is rule of law.

We further supplement these data sources with data from the International Telecommunication Union (ITU), "the United Nations specialized agency for information and communication technologies."[112] The variable we use from ITU is mobile broadband subscriptions per 100 people, which is available for the period 2007 to 2019.[113] Because mobile broadband adoption is our key variable of interest, this limits our analysis to the period 2007 to 2019.

We map countries to regions and development groups following the World Bank's most recent classification. The geographical regions we use are Asia Pacific (APAC); Europe; Latin America (LATAM); Middle East, North Africa and Turkey (MENAT); Sub-Saharan Africa (SSA); and the countries of Canada, India, and the United States. The development groups used are high income, upper-middle income, lower-middle income, and low income.[114]

**Figure 9** provides a complete list of the variables used in the analysis and their definitions and sources.

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111 The World Bank, "DataBank," available at https://databank.worldbank.org/home.aspx; The World Bank, "Data: Methodologies," available at https://datahelpdesk.worldbank.org/knowledgebase/articles/906531-methodologies; The World Bank, "Data: World Bank Country and Lending Groups," available at https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.

112 ITU, "About International Telecommunication Union (ITU)," available at https://www.itu.int/en/about/Pages/default.aspx.

113 ITU's definition of active mobile broadband subscriptions is as follows: "Active mobile-broadband subscriptions refers to the sum of active handset-based and computer-based (USB/dongles) mobile-broadband subscriptions to the public Internet. It covers actual subscribers, not potential subscribers, even though the latter may have broadband-enabled handsets. Subscriptions must include a recurring subscription fee or pass a usage requirement – users must have accessed the Internet in the last three months. It includes subscriptions to mobile-broadband networks that provide download speeds of at least 256 kbit/s (e.g. WCDMA [(3G)], HSPA [(3G)], CDMA2000 1x EV- DO [(3G)], WiMAX IEEE 802.16e [(4G-level)] and LTE [(4G)]), and excludes subscriptions that only have access to GPRS, EDGE and CDMA 1xRTT." *See* ITU, "WTI Indicators with Definitions," p. 12, available at https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Documents/Events/2017/Aug-aspstat2017/WTI_Indicators_with_Definitions_14Aug2017_final.pdf; Gartner Glossary, "WCDMA (Wideband Code Division Multiple Access)," *Gartner*, available at https://www.gartner.com/en/information-technology/glossary/wcdma-wideband-code-division-multiple-access; Electronics Notes, "What is HSPA: Tutorial," available at https://www.electronics-notes.com/articles/connectivity/3g-hspa/what-is-hspa-high-speed-packet-access-tutorial.php; Rohde & Schwarz, "CDMA2000® 1xEV-DO Technology," available at https://www.rohde-schwarz.com/nl/technologies/cellular/cdma2000-1xev-do/cdma2000-1xev-do-technology/cdma2000-1xev-do_55906.html; Electronics Notes, "WiMAX IEEE 802.16 technology tutorial," available at https://www.electronics-notes.com/articles/connectivity/wimax/what-is-wimax-802-16-technology-basics.php; T-Mobile, "What is LTE?" available at https://www.t-mobile.com/resources/what-is-lte.

114 The World Bank, "Data: World Bank Country and Lending Groups," available at https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.

**Figure 9. Variable Definitions and Sources**

| Variable | Variable Definition | Source |
|---|---|---|
| GDP | GDP per capita in constant 2015 USD. | World Bank's World Development Indicators (WDI) |
| Mobile broadband subscriptions per 100 people | The number of active mobile broadband subscriptions per 100 inhabitants. | International Telecommunication Union (ITU) |
| Fixed broadband subscriptions per 100 people | The number of fixed broadband subscriptions per 100 inhabitants; fixed broadband subscriptions are fixed subscriptions to high-speed access to the public Internet (via a TCP/IP connection) at downstream speeds of at least 256 kbits/s. | WDI |
| Patent applications per capita | The sum of resident-filed and non-resident-filed patent applications filed through the Patent Cooperation Treaty procedure or with a national patent office. | WDI |
| Secondary school enrollment | Secondary school gross enrollment ratio. This is the ratio of total students enrolled in secondary education (regardless of age) to the population of the age group that officially corresponds to secondary education. | WDI |
| Fertility rate | Total fertility rate, accounting for under-5 mortality. This is the average number of children that would be born to a woman - and survive to at least the age of 5 - if she were to live to the end of her childbearing years and bear children in accordance with age-specific fertility rates of the specified year. | WDI |
| Government expenditure | General government final consumption expenditure as a percent of GDP. | WDI |
| Gross capital formation | Gross capital formation as a percent of GDP; this includes outlays on additions to the fixed assets of the economy and net changes in the level of inventories. | WDI |
| Rule of law | An aggregate indicator representing perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence. | World Bank's Worldwide Governance Indicators (WGI) |

Note: All variables are taken directly from the World Bank and ITU with the exception of fertility rate, which is calculated as (total fertility rate)*(1-(under-5 mortality rate per 1,000 live births/1,000)).
Sources:
[1] World Bank.
[2] International Telecommunication Union.

## C. Summary statistics

Summary statistics on mobile technology adoption indicate that the level and rate of adoption varies across geographic regions and development groups.

**Figure 10** shows the average per-100-people adoption as well as the total adoption of mobile broadband technology and mobile cellular technology for the regions APAC, Canada, Europe, India, LATAM, MENAT, SSA and the United States in 2019. India and SSA exhibit the lowest per-100-people adoption of mobile broadband technology while the United States and Europe exhibit the highest per-100-people adoption, followed by APAC, Canada, MENAT, and LATAM.[115]

**Figure 10. Mobile Technology Adoption Levels by Region, 2019**

| Region | Mobile broadband subscriptions, per 100 people | Mobile broadband subscriptions, total | Mobile cellular subscriptions, per 100 people | Mobile cellular subscriptions, total |
|---|---|---|---|---|
| APAC | 90.85 | 2,354,872,494 | 122.18 | 3,295,242,494 |
| Canada | 82.71 | 30,941,000 | 91.86 | 34,366,950 |
| Europe | 101.83 | 711,257,090 | 130.12 | 965,024,449 |
| India | 47.04 | 642,799,000 | 84.27 | 1,151,480,361 |
| LATAM | 73.89 | 406,560,085 | 101.46 | 621,796,901 |
| MENAT | 75.61 | 380,207,693 | 112.70 | 567,163,300 |
| SSA | 37.37 | 331,515,809 | 87.22 | 796,208,509 |
| United States | 152.17 | 500,735,000 | 134.46 | 442,457,000 |

Sources:
[1] World Bank.
[2] International Telecommunications Union.

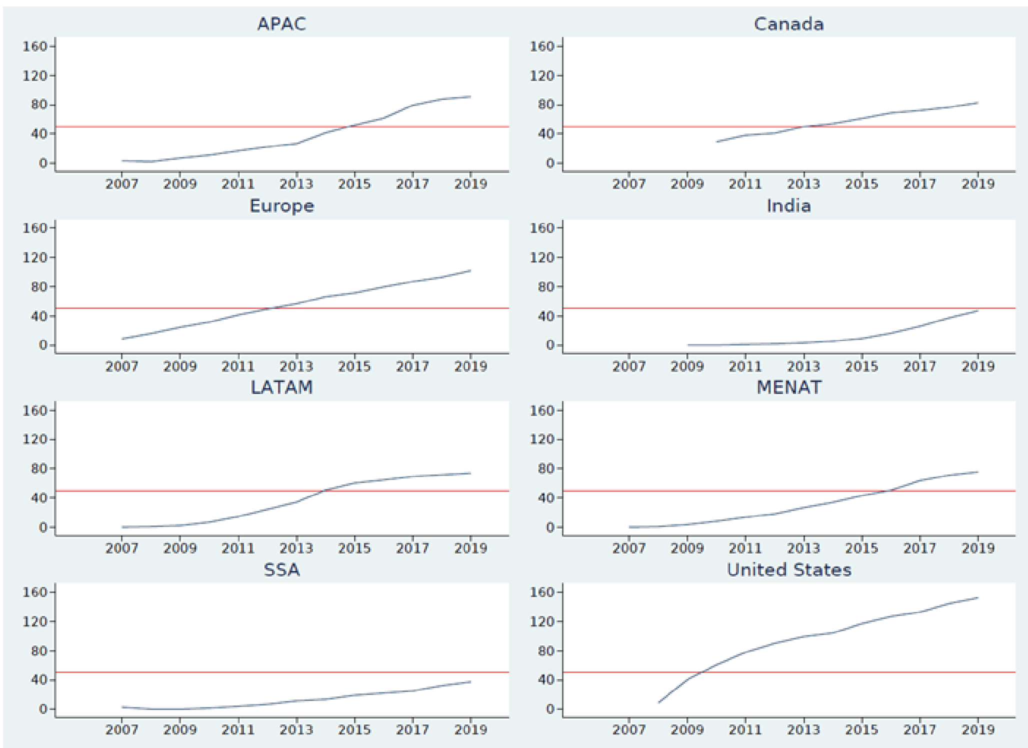
Mobile broadband subscriptions per 100 people is our preferred measure of mobile technology adoption due to its direct association with mobile access to the Internet.[116] As discussed above, we view adoption of mobile broadband (and the portable Internet access it provides, along with the more developed and widespread infrastructure that underlies mobile Internet access) as a closer analog to the metaverse than mobile cellular subscriptions alone.

115 Possible explanations for some regions exhibiting average adoption over 100 mobile broadband subscriptions per 100 people include (1) usage of multiple mobile devices, each with their own data plan and (2) usage of mobile devices with multi-SIM capabilities. Depending on the region (and provider), mobile broadband subscriptions may apply to a variety of wireless devices including basic phones, smartphones, tablets, netbooks, modems, mobile hotspot devices, smartwatches, and connected cars. Multi-SIM card phones allow users to activate multiple data plans and use multiple phone numbers on the same device (separately), whether for business, travel, or other purposes. Multi-SIM mobile devices are especially popular in Asia, with most Android handsets sold in China having two SIM slots and all iPhone 12 models sold in Japan being dual SIM (as of the end of 2020). In addition, multi-SIM devices are gaining popularity in India. *See* T-Mobile, “Policies: Open Internet,” available at https://www.t-mobile.com/responsibility/consumer-info/policies/internet-service; Verizon, “Important Information About Verizon Wireless Broadband Internet Access Services,” available at https://www.verizon.com/support/broadband-services/; Verizon, “Number Share - Mobile,” available at https://www.verizon.com/solutions-and-services/numbershare/; Verizon, “eSIM FAQs - Two numbers on one phone,” available at https://www.verizon.com/support/dual-sim-with-esim-faqs/#benefits; Apple, “Using Dual SIM with an eSIM,” available at https://support.apple.com/en-us/HT209044; Chiu, Karen, “Dual SIM slots and gold iPhones: Five ways Apple is embracing China,” *South China Morning Post,* September 12, 2018, available at https://www.scmp.com/abacus/tech/article/3028810/dual-sim-slots-and-gold-iphones-five-ways-apple-embracing-china; Apple Communities, “How can I buy dual SIM iPhone 12 Pro in Japan?” *Apple*, December 31, 2020, available at https://discussions.apple.com/thread/252250952; Nielsen, “Telecom Transitions: Tracking the Multi-SIM Phenomena in India,” *The Nielsen Company*, available at https://www.nielsen.com/wp-content/uploads/sites/3/2019/04/nielsen-featured-insights-tracking-the-multi-sim-phenomena-in-india.pdf.

116 Mobile broadband subscriptions per 100 people does not distinguish between prepaid and postpaid subscriptions and does not capture extent of usage (e.g., how people use their phones, how long they use their phones for); the definition only specifies that “[s]ubscriptions must include a recurring subscription fee or pass a usage requirement – users must have accessed the Internet in the last three months.” We therefore view mobile broadband subscriptions as a useful, though imperfect, proxy for mobile technology adoption. *See* ITU, “WTI Indicators with Definitions,” p. 2, available at https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Documents/Events/2017/Aug-aspstat2017/WTI_Indicators_with_Definitions_14Aug2017_final.pdf.

**Figure 11** shows how mobile broadband adoption grew from 2007-2019 for each region. An adoption level of 50 mobile broadband subscriptions per 100 people is shown in red as a point of reference. The figures show that different regions have experienced different rates of growth in mobile broadband adoption, even if adoption began at different points in time. Overall, regions and countries that exhibit higher mobile broadband adoption in 2019 also experienced faster growth in adoption, while regions and countries that exhibit lower mobile broadband adoption in 2019 also experienced slower growth in adoption. For example, the United States and Europe exhibit the highest mobile broadband adoption in 2019, and both regions progressed from zero to 50 mobile broadband subscriptions per 100 people in approximately five years or less. On the other hand, SSA and India exhibit the lowest mobile broadband adoption in 2019, and both regions progressed from zero to about 50 mobile broadband subscriptions per 100 people over approximately ten years.

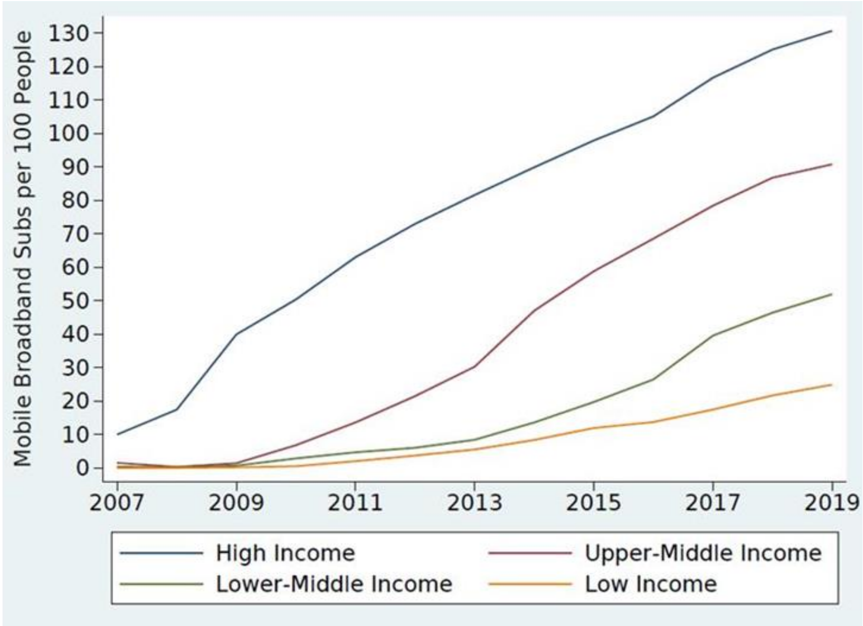
**Figure 11. Mobile Broadband Adoption by Region, 2007–2019**




Notes:
[1] Mobile broadband adoption is measured as the number of mobile broadband subscriptions per 100 people.
[2] The red line corresponds to 50 mobile broadband subscriptions per 100 people.
Sources:
[1] World Bank.
[2] International Telecommunication Union.

We also look at adoption by different categories of development defined by the World Bank, which reveals a monotonic relationship between income groups and mobile broadband adoption. **Figure 12** compares mobile broadband adoption for high income, upper-middle income, lower-middle income, and low-income countries from 2007 to 2019. At each point in time during this period, high-income countries exhibit the highest mobile broadband adoption, followed by upper-middle income countries, then lower-middle income countries, and, lastly, low-income countries.

**Figure 12. Mobile Broadband Adoption by Development Group, 2007–2019**




Note: As of the 2022 fiscal year, low-income economies are defined by the World Bank to be economies with a GNI per capita of $1,045 USD or less in 2020; lower middle-income economies are those with a GNI per capita between $1,046 and $4,095; upper middle-income economies are those with a GNI per capita between $4,096 and $12,695; high-income economies are economies with a GNI per capita of at least $12,696.
Sources:
[1] World Bank.
[2] International Telecommunication Union.
[3] The World Bank, "Data: World Bank Country and Lending Groups," available at https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

While the rest of our analysis focuses on global and regional results, these patterns indicate that to the extent different countries within a geographical region fall into different development groups, there may be significant heterogeneity in adoption and economic outcomes at the individual country level.

## D. Regression results

Turning to our regression results, we find a positive and statistically significant relationship between mobile broadband adoption and GDP that is robust to different estimation strategies.

**Figure 13** reports our main regression results. Column (1) reports results from estimating a basic pooled OLS model. The coefficient on the logged value of mobile broadband subscriptions per 100 people indicates that a 10% increase in mobile broadband adoption is associated with a 0.029 percentage point increase in GDP per capita growth. The other statistically significant covariates are government expenditure, which is negatively correlated with growth, and gross capital formation and rule of law, which are both positively correlated with growth.

Columns (2) and (3) report results from a country fixed effects model and the Arellano-Bond GMM model, respectively, both with robust standard errors. While both give statistically significant estimates for the coefficient of mobile broadband adoption, the fixed effects model estimate is slightly higher. A 10% increase in mobile broadband adoption is associated with a 0.099 percentage point increase in GDP growth in the fixed effects model and a 0.087 percentage point increase in GDP growth in the GMM model. The GMM estimation results in higher magnitude estimates for secondary enrollment, government expenditure, and gross capital formation. Government expenditure as a percent of GDP has a statistically significant negative correlation: a 1 percentage point increase in government expenditure's share of GDP is associated with a 0.0095 percentage point decrease in GDP per capita growth. This is perhaps because stimulus spending increases during economic downturns.[117]

**Figure 13. Relationship Between GDP Growth and Mobile Broadband Adoption**

| | (1) Pooled OLS | (2) FE | (3) GMM |
|---|---|---|---|
| Lag log GDP per capita | 0.9865*** | 0.8539*** | 0.7004*** |
| | (0.0022) | (0.0213) | (0.0564) |
| Log Mobile Broadband per 100 ppl | 0.0029*** | 0.0099*** | 0.0087** |
| | (0.0008) | (0.0020) | (0.0041) |
| Log Broadband per 100 ppl | 0.0018 | 0.0061 | 0.0225 |
| | (0.0016) | (0.0066) | (0.0154) |
| Log Patent | -0.0005 | 0.0028 | -0.0199 |
| | (0.0009) | (0.0040) | (0.0168) |
| Secondary Enrollment | 0.0001* | 0.0003 | 0.0009** |
| | (0.0001) | (0.0002) | (0.0004) |
| Fertility | -0.0027 | 0.0097 | -0.0399 |
| | (0.0023) | (0.0165) | (0.0248) |
| Gov Expenditure / GDP | -0.0020*** | -0.0078*** | -0.0095*** |
| | (0.0002) | (0.0016) | (0.0020) |
| Gross Capital Formation / GDP | 0.0008*** | 0.0017** | 0.0037*** |
| | (0.0001) | (0.0007) | (0.0011) |
| Rule of Law | 0.0093*** | 0.0057 | 0.0150 |
| | (0.0019) | (0.0113) | (0.0135) |
| Constant | 0.1291*** | 1.3917*** | |
| | (0.0246) | (0.1977) | |
| Observations | 838 | 838 | 683 |
| R-squared | 0.9996 | 0.9267 | |
| Number of countries | | 107 | 99 |
| AR(1) | | | 0.0154 |
| AR(2) | | | 0.118 |
| Hansen | | | 0.0947 |
| Instrument Count | | | 64 |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In the GMM estimation, a total of 64 instruments are used.[118] The rows AR(1) and AR(2) are the p-values of the test for autocorrelation of order one and two, respectively. The test exhibits evidence of autocorrelation of order one but fails to reject the null hypothesis of no autocorrelation of order two. Hence, the test indicates that it is appropriate to use second lags as instruments. The Hansen test is a test of the null hypothesis that the

117 Additionally, we estimated a regression specification where government expenditure and gross capital formation are treated as endogenous variables, using their second lags as instruments. The coefficient for mobile broadband is 0.0104 with p-value <0.01. The Hansen test and autoregression test confirmed instrument validity and the lack of autoregression of degree two.

118 The 64 instruments include the eleven second lags of mobile broadband, the twelve second lags for each of log GDP per capita, log broadband, and log patent, the twelve third lags of GDP per capita, and the five exogenous variables. Mobile broadband subscriptions per 100 people is only available from 2007-2019, so the maximum number of second lags is 11. GDP, patents, and broadband are available before 2007, so they each have 12 second lags.

instruments are independently distributed of the error process. With a p-value of 0.095, the Hansen test of overidentifying restrictions fails to reject the null hypothesis $E(Z'\Delta\epsilon) = 0$, providing support for the validity of the instruments.

## E. Robustness

To check that the lags we have chosen form an appropriate set of instruments, we ran two alternative specifications with different lags as instruments. If the Hansen test returns a p-value less than 0.05, then the alternative specification does not have valid instruments.

**Figure 14** reports the results of these robustness checks. Column (1) repeats the baseline model results from column (3) of Figure 13 for reference. Column (2) reports results that instrument log GDP per capita with only its second lags instead of both second and third lags, which reduces the number of instruments to 52. The coefficient on mobile broadband adoption is similar to the baseline case, but the Hansen test p-value is only 0.0301, which indicates that the model may be mis-specified without the third lags of GDP per capita as instruments. Column (3) reports results for a specification in which mobile broadband adoption, fixed broadband adoption, and patent application are instrumented with their third lags instead of second lags. The coefficient on mobile broadband adoption is smaller in magnitude and not statistically significant in this specification.

**Figure 14. Robustness: Alternative Lags as Instruments**

| | (1)<br>Baseline GMM | (2)<br>Lag 2 | (3)<br>Lag 3 |
|---|---|---|---|
| Lag GDP per capita | 0.7004*** | 0.6815*** | 0.6577*** |
| | (0.0564) | (0.0683) | (0.0603) |
| Log Mobile Broadband per 100 ppl | 0.0087** | 0.0089* | 0.0061 |
| | (0.0041) | (0.0047) | (0.0057) |
| Log Broadband per 100 ppl | 0.0225 | 0.0236 | 0.0420 |
| | (0.0154) | (0.0177) | (0.0277) |
| Log Patent | -0.0199 | -0.0154 | -0.0298 |
| | (0.0168) | (0.0177) | (0.0182) |
| Secondary Enrollment | 0.0009** | 0.0009** | 0.0009** |
| | (0.0004) | (0.0004) | (0.0004) |
| Fertility | -0.0399 | -0.0496* | -0.0515* |
| | (0.0248) | (0.0294) | (0.0280) |
| Gov Expenditure / GDP | -0.0095*** | -0.0093*** | -0.0094*** |
| | (0.0020) | (0.0024) | (0.0023) |
| Gross Capital Formation / GDP | 0.0037*** | 0.0037*** | 0.0036*** |
| | (0.0011) | (0.0011) | (0.0011) |
| Rule of Law | 0.0150 | 0.0085 | 0.0195 |
| | (0.0135) | (0.0135) | (0.0121) |
| Observations | 683 | 683 | 683 |
| Number of countries | 99 | 99 | 99 |
| AR(1) | 0.0154 | 0.0261 | 0.0523 |
| AR(2) | 0.118 | 0.165 | 0.177 |
| Hansen | 0.0947 | 0.0301 | 0.188 |
| Instrument Count | 64 | 52 | 63 |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We conclude from these robustness checks that GDP per capita should be instrumented with both its second and third lags, while the technology variables should be instrumented with the second lags only, consistent with the baseline GMM model reported in Figure 13. The model reported in Figure 13, column (3) therefore reflects our preferred specification, and our main finding from this analysis is that a 10% increase in mobile technology adoption is associated with a 0.087 percentage point increase in GDP growth. In the next section, we apply this finding to quantify the potential economic impact of the metaverse.

# V. Analysis of the Potential Economic Impact of the Metaverse

In this section, we draw on our economic analysis of mobile technology as a model for the potential economic impact of the metaverse, measured in terms of GDP. We find that if the metaverse were to be adopted and grow in a similar way as mobile technology, then we would expect it to be associated with a 2.8% contribution to global GDP after 10 years.

## A. Quantification of the potential impact of the metaverse on GDP

We quantify the potential impact of the metaverse on GDP by applying the model of mobile technology from Section IV in two steps.

First, we calculate a single statistic that summarizes the level and speed of mobile technology adoption: the compound annual growth rate (CAGR) of mobile broadband subscriptions per 100 people over the 2007-2019 sample period. **Figure 15** reports this statistic globally and for each region. Globally, mobile broadband adoption increased from 6.2 to 76.9 subscriptions per one hundred people between 2007 and 2019, implying a global CAGR of mobile technology adoption of 23.3%. By region, the CAGR of mobile technology adoption ranges from 12.2% in Canada to 83.9% in MENAT.[119] We use these observed growth rates in mobile technology adoption as the assumed growth rates for metaverse adoption.

**Figure 15. Mobile Technology Adoption by Region, 2007–2019**

| Region | Starting Level of Adoption (per 100 people) [A] | Ending Level of Adoption (per 100 people) [B] | Years of Adoption [C] | Compound Annual Growth Rate of Adoption [D] |
|---|---|---|---|---|
| APAC | 3.5 | 90.8 | 13 | 31.2% |
| Canada | 29.4 | 82.7 | 10 | 12.2% |
| Europe | 8.8 | 101.8 | 13 | 22.6% |
| India | 0.9 | 47.0 | 9 | 63.1% |
| LATAM | 0.2 | 73.9 | 13 | 66.9% |
| MENAT | 0.1 | 75.6 | 13 | 83.9% |
| SSA | 3.0 | 37.4 | 13 | 23.5% |
| United States | 8.7 | 152.2 | 12 | 29.7% |
| Global | 6.2 | 76.9 | 13 | 23.3% |

Notes:
[1] Due to variation in data coverage over time, starting and ending adoption levels for a region may not cover the exact same set of countries.
[2] Years of adoption is the number of years of available adoption data.
[3] Compound annual growth rate is calculated as [D] = ([B] ÷ [A]) ^ (1 ÷ ([C]–1)) – 1.
Sources:
[1] World Bank.
[2] International Telecommunication Union.

Second, we calculate the contribution of the metaverse to GDP in the 10 years following the beginning of adoption, assuming that a small increase in metaverse adoption has the same marginal impact on GDP growth as a small increase in mobile broadband adoption. We assume that GDP will continue its growth trend from the most recent ten years of available data (2009-2019), and we calculate the difference in GDP after 10 years with and without the metaverse. The calculation can be derived as follows.

119 The ITU mobile broadband data for Canada begins in 2010. Considering Canada and the United States most likely started using mobile broadband around the same time in 2007, the calculated CAGR for Canada of 12.2% would be an underestimate. Canada also has lower adoption rates than the United States by 2019, 82.7 and 152.2 respectively. Hence, the actual CAGR of adoption for Canada is likely between 12.2% and the United States' 29.7%.

Let $\gamma$ be the annual secular growth rate of GDP. Let $r = CAGR_{adoption} \cdot \beta$ be the additional annual growth in GDP attributable to the metaverse, which is given by the product of the CAGR of adoption (assumed to be equal to the CAGR of mobile technology adoption) and the estimated coefficient of 0.0087 from our regression of GDP growth on mobile broadband adoption (see Figure 13, column 3). Let $G_0$ be the level of GDP at the start of metaverse adoption. Without the metaverse, the GDP after 10 years is given by $G_0(1+\gamma)^9$. With the metaverse, the GDP after 10 years is given by $G_0(1+\gamma+r)^9$. The share of total GDP attributable to the metaverse after 10 years is therefore given by:

$$Metaverse\text{'}s\ Share\ of\ 10th\ Year\ GDP = \frac{(1+\gamma+r)^9 - (1+\gamma)^9}{(1+\gamma+r)^9} \quad (2)$$

The metaverse's share of GDP in the 10th year following the beginning of its adoption does not depend on any assumption about when adoption begins. For ease of interpretation, we also calculate the metaverse's total contribution to GDP in dollars after 10 years assuming the metaverse exists today. Letting $G_0$ be 2022 GDP. Assuming metaverse adoption begins in 2022, then the metaverse's total dollar contribution to GDP in 2031 would be given by:

$$Metaverse\text{'}s\ Total\ Contribution\ to\ GDP\ in\ 2031\ (\$) = G_0(1+\gamma+r)^9 - G_0(1+\gamma)^9 \quad (3)$$

Equation 3 says that the metaverse's contribution to GDP in 2031 is the difference between GDP in 2031 with the metaverse and GDP in 2031 without the metaverse.[120]

**Figure 16** summarizes the results of these calculations. Our model implies that the metaverse's share of global GDP in the 10th year is 2.8%. By region, the metaverse's share of regional GDP in the 10th year is 2.3% for APAC, 0.9% for Canada,[121] 1.7% for Europe, 4.6% for India, 5.0% for LATAM, 6.2% for MENAT, 1.8% for SSA, and 2.3% for the United States. Because these numbers do not account for any displacement of GDP from other industries that may occur over the 10-year period, they can be viewed as a lower bound on the metaverse's share of 10th year GDP.

120 Another way to conceptualize the calculation is that in each year between 2022 and 2031, the metaverse contributes a small amount of incremental growth to GDP that otherwise would not exist without the metaverse. We assume this small amount of incremental growth that the metaverse adds to GDP each year persists over time and continues to be associated with the metaverse. Equation 3 is roughly equal to the sum of these small incremental annual contributions to GDP, but with compounding.

121 Because the CAGR of adoption for Canada is likely understated due to limited data availability (as noted above), the implied contribution of the metaverse to GDP in Canada is likely also understated.

**Figure 16. Contribution to GDP from the Metaverse in 10 Years**

| Region | Assumed Secular GDP Growth [E] | Metaverse's Share of 10th Year GDP [F] | Metaverse's Total Contribution to GDP in 2031 ($ Trillions) [G] |
|---|---|---|---|
| APAC | 4.3% | 2.3% | $1.04 |
| Canada | 1.1% | 0.9% | $0.02 |
| Europe | 1.5% | 1.7% | $0.44 |
| India | 5.4% | 4.6% | $0.24 |
| LATAM | 1.1% | 5.0% | $0.32 |
| MENAT | 1.9% | 6.2% | $0.36 |
| SSA | 1.0% | 1.8% | $0.04 |
| United States | 1.6% | 2.3% | $0.56 |
| Global | 2.0% | 2.8% | $3.01 |

Notes:
[1] Assumed secular GDP growth rate is the compound annual growth rate of GDP over the 2009-2019 period.
[2] The implied increase in GDP as a share of 10th year GDP is calculated from equation 2, where $\gamma$ is given by column (E) and $r$ is given by the product of column (D) from Figure 15 and the estimated coefficient on log mobile broadband per 100 people from Figure 13, column (3).
[3] The total contribution to GDP in 2031 is calculated as the product of column [F] and projected GDP in 2031 with the metaverse, which is equivalent to equation 3.
Source: World Bank.

We can contextualize our results against existing projections of the economic potential of the metaverse by assuming that the metaverse existed today and calculating the contribution to GDP after 10 years in dollars. Our model implies that if metaverse adoption were to begin in 2022, then the metaverse's total contribution to global GDP in 2031 would be $3.01 trillion (measured in 2015 U.S. dollars), one third of which, or $1.04 trillion, is attributable to APAC.[122] Additionally, contributions to Canada, Europe, India, LATAM, MENAT, SSA, and the United States GDP are $0.02, $0.44, $0.24, $0.32, $0.36, $0.04, and $0.56 trillions, respectively.

The global estimate lies within the range of existing projections. Industry analysts and observers have offered a wide range of estimates for the potential valuation or addressable market size of the metaverse. Near-term estimates range from about $800 billion[123] to upwards of $2 trillion[124] over the next few years.[125] Long-term

122 The $3.01 trillion figure is based on projected world GDP in 2031 accounting for secular growth and growth associated with the metaverse, which is approximately $104.97 trillion in 2015 U.S. dollars. This estimate does not account for population growth and therefore likely understates the metaverse's potential contribution to GDP.

123 Bloomberg Intelligence estimates the Metaverse market "may reach $783.3 billion in 2024." A majority of the estimated Metaverse market value in 2024 is attributed to the gaming sector – particularly the gaming software, services, and hardware sectors – and the live entertainment sector (e.g., films, live music and sports).

124 According to Business Insider, Bernstein analysts have estimated "the size of metaverse-related markets to be $2 trillion and growing." Yahoo Finance and Nasdaq have both reported on this same estimate, with Yahoo Finance quoting Bernstein's claim that "[t]he combined annual run-rate of the most relevant markets is $2 trillion and growing."

125 Bloomberg Intelligence, "Metaverse may be $800 billion market, next tech platform," *Bloomberg*, December 1, 2021, available at https://www.bloomberg.com/professional/blog/metaverse-may-be-800-billion-market-next-tech-platform/; Huang, Vicky G., "Wall Street analysts are rushing to dub the metaverse the next multi-trillion-dollar investing opportunity. Here's what 3 of them are saying about its potential and risks," *Business Insider*, December 11, 2021, available at https://www.businessinsider.com/metaverse-stocks-tokens-altcoins-wall-street-crypto-gamefi-facebook-roblox-2021-12; Mozée, Carla, "Major brand names from Microsoft to Bumble have said they're getting into the metaverse. Here are 5 household names making plans for Web3," *Yahoo!Finance*, December 9, 2021, available at https://finance.yahoo.com/news/major-brand-names-microsoft-bumble-182626579.html; Saintvilus, Richard, "Who Will Win the Battle for the Metaverse?" *Nasdaq*, December 13, 2021, available at https://www.nasdaq.com/articles/who-will-win-the-battle-for-the-metaverse.

estimates range from approximately $3 trillion to $30 trillion by the time the metaverse reaches widespread adoption, with the most optimistic estimate being over $80 trillion.[126] A number of sources project that a mature metaverse could be a multitrillion-dollar industry, though they do not estimate the amount of time needed for the metaverse to reach maturity.[127] If metaverse adoption were to begin today, our estimate of a $3.01 trillion (in 2015 U.S. dollars) contribution to global GDP in 2031 would be on the high end of the near-term projections, consistent with our ten-year time horizon being longer than that of the near-term projections. On the other hand, our estimate is on the lower end of the long-term projections, which may reflect, at least in part, that our analysis is based on growth in GDP associated with the metaverse and does not account for any displacement of GDP that is currently attributable to other industries or sectors.[128]

## B. Challenges and opportunities for metaverse adoption

The metaverse is still in an early stage, with many contributors from around the world helping to plan its inclusive design and construction.[129] We are currently witnessing the early phases of development, including the rolling out of infrastructure and technologies that will likely support the metaverse. The extent to which the economic potential of the metaverse is realized depends on how effectively the necessary infrastructure and technology are developed and deployed, as well as how widely the new technology is adopted by consumers and businesses—that is, whether the metaverse can make it past the “Trough of Disillusionment” and onto the “Slope of Enlightenment.” Once the infrastructure is in place and adoption is underway, it opens the door for the development of endless endeavors built by creators, developers and businesses, as has been the case with the Internet and mobile technology.

In the rest of this section, we discuss more concretely some of the challenges and opportunities for the metaverse in achieving its potential.

**Infrastructure and technology requirements.** The metaverse will require many new technologies, innovations, and discoveries before it can be fully realized. New metaverse-specific protocols will evolve, new companies and

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126 Goldman Sachs, “Framing the Future of Web 3.0: Metaverse Edition,” December 10, 2021, available at https://www.goldmansachs.com/insights/pages/gs-research/framing-the-future-of-web-3.0-metaverse-edition/report.pdf; Speights, Keith, “3 Stocks to Buy With a $30 Trillion Metaverse Market on the Way,” *The Motley Fool,* December 6, 2021, available at https://www.fool.com/investing/2021/12/06/3-stocks-to-buy-with-a-30-trillion-Metaverse-marke/.

127 *See, e.g.,* Kim, Sohee, “Metaverse Is a Multitrillion-Dollar Opportunity, Epic CEO Says,” *Bloomberg,* November 17, 2021, available at https://www.bloomberg.com/news/articles/2021-11-17/Metaverse-is-a-multitrillion-dollar-opportunity-epic-ceo-says?sref=GzMobW41; Logan, Kylie, “Cathie Wood says the Metaverse could be worth trillions and will affect the world in ways ‘we cannot even imagine right now,’” *Fortune,* December 3, 2021, available at https://fortune.com/2021/12/03/cathie-wood-Metaverse-trillions-affect-every-sector/; Cook, John, “We asked seven venture capitalists if the Metaverse is the next big thing or just a lot of hype,” *GeekWire,* November 23, 2021, (“Geekwire”), available at https://www.geekwire.com/2021/we-asked-seven-venture-capitalists-if-the-Metaverse-is-the-next-big-thing-or-just-a-lot-of-hype/; Huang, Vicky G., “Wall Street analysts are rushing to dub the metaverse the next multi-trillion-dollar investing opportunity. Here’s what 3 of them are saying about its potential and risks,” *Business Insider*, December 11, 2021, available at https://www.businessinsider.com/metaverse-stocks-tokens-altcoins-wall-street-crypto-gamefi-facebook-roblox-2021-12; Goldman Sachs, “Framing the Future of Web 3.0: Metaverse Edition,” December 10, 2021, available at https://www.goldmansachs.com/insights/pages/gs-research/framing-the-future-of-web-3.0-metaverse-edition/report.pdf.

128 Similarly, the GSMA’s estimate of the mobile economy’s contribution to global GDP of $4.4 trillion (5.1%) in 2020 accounts for any displacement of other industries that has occurred over time, whereas our estimate of the metaverse’s contribution to global GDP is based on new growth in GDP and not displacement of existing industries.

129 Facebook, Inc. (now Meta Platforms, Inc.), “Second Quarter 2021 Results Conference Call,” July 28, 2021, available at https://s21.q4cdn.com/399680738/files/doc_financials/2021/q2/FB-Q2-2021-Earnings-Call-Transcript.pdf, p. 4 (“[Mark Zuckerberg, CEO]: [I]t's going to take a lot of work, and no company is going to be able to build this all by themselves.”).

innovations will come into existence, and new industries will emerge that directly or indirectly sustain or are sustained by the metaverse.

Technology expert and venture capitalist Matthew Ball has outlined three core elements that need to come into place for the metaverse to actualize: concurrency infrastructure, the adoption of standards and protocols, and the on-ramp experience.[130]

Concurrency infrastructure refers to the technology that will support the simultaneous presence of millions of users in a shared synchronous experience. The metaverse will require computational infrastructure to enable many-to-many server connections that can interact persistently and concurrently, in contrast with the current Internet infrastructure of one-to-one server connections.[131]

Standards and protocols will also be needed to actualize the level of interoperability envisioned for the metaverse. One company or a handful of companies will not own or be the metaverse; rather, individual companies' products will be destinations in the metaverse or support the metaverse. Achieving this level of interoperability will require collaboration on a massive scale, including consolidation and uniformity of the existing protocols and standards[132] as well as creation of (and agreement on) new protocols and standards.[133]

And finally, the on-ramp experience requires critical-mass adoption of the metaverse by creators. Ball uses an analogy of a newly built shopping mall: sellers and buyers are not going to rush to the mall unless there are advantages and attractions for all of them. So, unless the metaverse has something exciting to offer both creators and users, it may be challenging to achieve widespread adoption of the metaverse may be a challenge to overcome.[134]

The development and adoption of hardware and software also present potential challenges for metaverse adoption and retention.[135] With respect to hardware, for the metaverse based on VR technologies to become successful on a similar level as personal computers and mobile phones, the vast adoption of hardware pieces such as VR

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130 Ball, Matthew, "The Metaverse: What It Is, Where to Find it, and Who Will Build It," matthewball.vc, January 13, 2020, available at https://www.matthewball.vc/all/themetaverse.

131 Ball, Matthew, "The Metaverse: What It Is, Where to Find it, and Who Will Build It," matthewball.vc, January 13, 2020, available at https://www.matthewball.vc/all/themetaverse.

132 Specifically, Ball believes the standard set of what is "accepted" for a given function, file, etc., will need to be smaller than current sets to support interoperability and live synchronous experiences. For example, companies including Amazon, Meta and Google currently use technologies that are similar but do not "transition into one another," and Ball seems to suggest that, in order for the metaverse to be interoperable and synchronous, the set of such technologies should be narrowed down such that it is easier to transition between different platforms. *See* Ball, Matthew, "The Metaverse: What It Is, Where to Find it, and Who Will Build It," matthewball.vc, January 13, 2020, available at https://www.matthewball.vc/all/themetaverse ("The Metaverse will require an even broader, more complex, and resilient set of S&Ps. What's more, the importance of interoperability and live synchronous experiences means we'll need to prune some existing standards and "standardize" around a smaller set per function. Today, for example, there are a multitude of image file formats: .GIF, .JPEG, .PNG, .BMP, .TIFF, .WEBP, etc. And while the web today is built on open standards, much of it is closed and proprietary. Amazon and Facebook and Google use similar technologies, but they aren't designed to transition into one another — just as Ford's wheels aren't designed to fit a GM chassis.").

133 *See* Ball, Matthew, "The Metaverse: What It Is, Where to Find it, and Who Will Build It," matthewball.vc, January 13, 2020, available at https://www.matthewball.vc/all/themetaverse. *See also* Monier, Stephane, "Special Report – Metaverse: overhyped or the next internet revolution?" Lombard Odier, December 21, 2021, available at https://www.lombardodier.com/contents/corporate-news/investment-insights/2021/december/special-report--metaverse-overhy.html.

134 Ball, Matthew, "The Metaverse: What It Is, Where to Find it, and Who Will Build It," matthewball.vc, January 13, 2020, available at https://www.matthewball.vc/all/themetaverse.

135 Sevilla, Gadjo, "Hardware is the key to metaverse adoption—software is the key to retention," eMarketer, January 25, 2022, available at https://www.emarketer.com/content/hardware-key-metaverse-adoption-software-key-retention/ ("eMarketer on metaverse adoption").

headsets and controllers is required. The adoption rate of VR headsets is expected to depend on price, ease of use, proliferation of apps, and user experience in the virtual environment.[136] Early users of VR hardware have complained about the headsets being hot, uncomfortable, having subpar battery life, and being difficult to operate with eyeglasses, and it is unclear how much time per day users will be willing to wear VR headsets.

Software and operating systems for VR headsets are expected to remain one of the biggest challenges influencing adoption and retention. Current users of smartphones and personal computers are used to typing information on a screen, which in VR is replaced by a 40-inch virtual floating keyboard.[137] Fundamental functions such as messaging, searching, moving files are currently multistep processes that confuse even the most technically advanced users.[138] Moreover, it takes time, and with a two-hour battery life limit, the VR experience can become frustrating for users unless software and operating systems quickly develop and address these challenges.[139]

Developing a seamless user experience for the metaverse is expected to take time and is anticipated to materialize in phases, as more individual and business users adopt the technology.

**Other factors.** Metaverse adoption may also face country- or regional-specific challenges in the form of governing bodies' policy or regulatory objectives. In 2021, the AR/VR Policy Conference organized by The Information Technology and Innovation Foundation (ITIF), and The XR Association hosted expert talks and panels on "explor[ing] the role of policy in AR/VR innovation and identify[ing] priority areas for policymakers to consider as these technologies continue to expand."[140] A main takeaway from the conference was that data supervision and management—including establishing digital safety and personal privacy standards from the outset—is a key policy concern for AR/VR, given the substantial volume of information about individuals and their environment required to deliver immersive, engaging experiences.[141]

For example, the European Union is in the process of finalizing digital competition and content moderation laws (the Digital Markets Act (DMA) and Digital Services Act (DSA)) that would require digital platforms to better support digital competition and regulate the content on their platforms to prevent the spread of harmful and/or illegal content and products. Specifically, these laws require platforms to disclose more information to their users. For example, social media platforms would need to tell users if the visibility of certain content was restricted, and e-commerce platforms would need to invest more resources into vendor identity verification to curb sales of illegal or harmful products. Notably, Human Rights Watch has pointed out that, as the DMA and DSA defer to existing EU and national laws on defining "illegal" content, these laws could potentially facilitate government censorship in the digital world.[142]

Individual companies are also voicing their concerns given the increasing proliferation of AR/VR in homes and classrooms. Some have emphasized the importance of safeguarding children's physical and emotional wellbeing,

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136 eMarketer on metaverse adoption.

137 eMarketer on metaverse adoption.

138 eMarketer on metaverse adoption.

139 eMarketer on metaverse adoption.

140 "The Augmented and Virtual Reality Policy Conference" *ARVR Policy Conference*, available at https://www.arvrpolicy.org/.

141 Dick, Ellysse, "Public Policy for the Metaverse: Key Takeaways from the 2021 AR/VR Policy Conference," November 15, 2021, available at https://itif.org/publications/2021/11/15/public-policy-metaverse-key-takeaways-2021-arvr-policy-conference/ ("AR/VR Policy Conference").

142 Human Rights Watch, "EU: Put Fundamental Rights at Top of Digital Regulation," January 7, 2022, available at https://www.hrw.org/news/2022/01/07/eu-put-fundamental-rights-top-digital-regulation. The article discusses additional concerns as well.

while others have raised that bad actors can exploit and abuse AR/VR to “change reality.”[143] For example, Roblox emphasized during their Q2 2021 earnings call that the metaverse must be a platform that is both “civil and safe” for children while remaining interesting to adults, and that safety is a top priority for Roblox in integrating voice and video communications.[144] Roblox highlighted that building “policy-aware” and law-abiding platforms with law-abiding content creators and developers is another key priority.[145] An implication is that building an accessible, inclusive, and safe metaverse is going to play a vital role in accelerating its adoption and enabling further development of its innovative technologies.

# VI. Conclusion

Economic theories of innovation and empirical evidence of the impacts of mobile technology and other successful technological innovations of the past 20$^{th}$ century indicate that the metaverse has the potential to have substantial, beneficial economic impacts in multiple dimensions—including contributing to GDP growth, creating jobs, increasing productivity, and improving consumer welfare through other dimensions in both developed and developing countries.

Our empirical analysis provides an aggregate measure of the metaverse’s total potential contribution to GDP over a medium-term time horizon—suggesting that if the metaverse were to be adopted and grow in a similar way as mobile technology, then we would expect it to be associated with a 2.8% contribution to global GDP after 10 years. However, the impacts of the metaverse are likely to be felt differently in different sectors of the economy, in different regions, at different points in time, and for different people. And over time, if the metaverse is successful, it will likely displace some existing technologies and industries, as prior technologies have done before. A direction for future research is to quantify these heterogeneous impacts and measure the potential displacement of industries and restructuring of local economies that may accompany the growth of the metaverse.

Current public commentary about the metaverse indicates that many pieces still need to come together to make the metaverse a reality and that businesses, consumers, creators, and policymakers will together contribute to its success. With successful development and deployment of infrastructure and other technologies, policies that support widespread and equitable distribution and uses of the metaverse, and endless creative innovations built on top of the foundational technology, the metaverse can be expected to have substantial beneficial economic impacts around the world.

143 AR/VR Policy Conference.

144 Roblox Q2 2021 Earnings Call, p. 10, available at https://s27.q4cdn.com/984876518/files/doc_financials/2021/q2/final-081721-q4-roblox-corporation-q2-2021-earnings-1067544.pdf (“Roblox Q2 2021 Earnings Call”).

145 Roblox Q2 2021 Earnings Call.

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