

The Global Economic Impacts Associated with Virtual and Augmented Reality

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I. Introduction

This study estimates the projected global economic impacts associated with the spread of virtual and augmented reality (“VR/AR”) technology over the next five years. Virtual reality (“VR”) describes a three-dimensional, computer-generated environment in which a person can become immersed. That is, the environment can be explored and is dynamic, and thus a person can interact with his or her surroundings. Obvious applications for VR include gaming and other forms of video and entertainment (e.g., viewing television programs and movies), while other anticipated uses include military simulations, improved educational experiences, skill development for healthcare professionals, and enhanced shopping and advertising opportunities.²

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. ABIresearch projects AR to be about half the size of VR in terms of units shipped over the next five years, and forecasts that gaming and entertainment will be less prominent for AR, accounting for 21 percent of unit shipments over the same time period. ABIresearch’s largest projected areas for AR are medicine, including surgery and diagnosis (35 percent), and industrial applications related to logistics, automotive work, and factory floors (31 percent).³ Other examples of applications for AR include enhanced navigation that uses a phone’s camera in combination with GPS information, reporting aircraft instrumentation information to a military pilot, enhanced education in schools and for other occupational training, location-based advertising campaigns, and augmented shopping experiences.⁴

In estimating the projected economic impacts associated with a new innovation such as VR/AR, it is important to note that when a given innovation is first released to the market, such as the personal computer, its success is difficult to predict. In particular, at the time of its introduction, it is unclear in which areas it will be used, the extent of its adoption, and the technologies and related ecosystems that will be developed that build upon it.

¹ The authors are all employed by Analysis Group, Inc. Funding for this study was provided by Facebook, Inc.

² See <http://www.techrepublic.com/article/9-industries-using-virtual-reality/>;
<http://www.socialmediatoday.com/content/how-ecommerce-augmented-and-virtual-reality-will-redefine-retail-experience>.

³ ABIresearch, “Gaming, Augmented, and Virtual Reality Market Data Release,” Q3, 2015.

⁴ *Id*; http://newtech.about.com/od/softwaredevelopment/a/Applications-Of-Augmented-Reality_2.htm;
<http://www.socialmediatoday.com/content/how-ecommerce-augmented-and-virtual-reality-will-redefine-retail-experience>.

For the above reasons, it is challenging to predict the economic potential of VR/AR. To address this challenge, we utilize a range of approaches and potential adoption scenarios to characterize the inherent uncertainty in any economic potential estimates. We first consider a “conservative approach” that estimates economic impact only in the form of revenues from VR/AR headset sales. We then consider a more optimistic “comparable approach” that infers additional economic impacts that could be realized as a result of VR/AR adoption based on observed impacts associated with similar devices, namely smartphones and tablets.

For both of these approaches, we consider a range of VR/AR adoption forecasts representing a plausible set of possible scenarios that could be realized over the next five years, from a low-end based on adoption by only “innovators” to a high-end estimate based on more widespread adoption. In doing so, our analysis of economic impact relies on third party forecasts of VR/AR units over the next five years. Such forecasts are estimates based on numerous assumptions including the potential addressable market for VR/AR, adoption rates, and applications where VR/AR is projected to be successful. Given the need to make a number of assumptions, there exists a wide range of estimates for the spread of VR/AR technology. As an example, ABIresearch forecasts 52.4 million VR and AR global unit shipments in 2016-2018, with 35.7 million of those for VR and 16.7 million for AR. Over the next five years through 2020, that forecast increases to 160 million total units shipped, with VR accounting for 107 million and AR, 53 million.⁵ In contrast, an alternate forecast by KZero predicts 80.2 million VR units corresponding to \$10.9 billion over the 2016-2018 period.⁶ Yet another forecast by UBS predicts only approximately 17 million worldwide VR device shipments over the same period, reaching approximately 72 million over the five year period from 2016-2020.⁷

While we do not endorse any one set of forecasts, our analysis relies on choosing a set of unit forecasts from which to estimate economic impact. In order to consider a range of plausible scenarios over the next five years, we rely on forecasts developed by ABIresearch,⁸ a technology market intelligence company, but adjust them to represent three possible groups that could adopt VR/AR in that time frame: a lower bound scenario in which only innovators purchase VR/AR, a medium scenario in which both innovators and early adopters purchase VR/AR, and an upper bound scenario of more widespread adoption including innovators, early adopters and an early majority.⁹ We refer to these as low, medium, and high adoption scenarios. Our adjustments to the ABIresearch forecasts

⁵ ABIresearch, "Gaming, Augmented, and Virtual Reality Market Data Release," Q3, 2015.

⁶ KZero Worldwide, "VR Market Sizing," at Slides 11 and 18.

⁷ See <http://www.ft.com/intl/cms/s/2/dae861ee-b275-11e5-b147-e5e5bba42e51.html>.

⁸ ABIresearch's VR estimates are based on conversations with companies, early sales for released models and developer kits, planned released dates, and industry knowledge. Their AR estimates are also based on conversations with potential enterprise customers. In some cases, estimates may be understated; for example, Google Cardboard alone has already surpassed ABIresearch's forecast of 2.6 million VR Mobile device units in 2014-2015, having sold 5 million units to date. See http://mashable.com/2016/01/27/google-cardboard-user-numbers/?utm_cid=mash-prod-nav-sub-st#sEH0EjJNFqqn.

⁹ The terms “innovators,” “early adopters,” and “early majority” are used to conform to the terminology used by KZero.

are based on KZero’s segmentation of its VR forecasts into these three groups, which are based on technology adoption customer segments identified in Everett Roger’s landmark study *Diffusion of Innovations*.¹⁰ KZero forecasts that in 2016 innovators will represent 14% of VR units, dropping to 12% in 2017 and 11% in 2018; while both innovators and early adopters will represent 52%, 45%, and 42% of units in those years, respectively.

In order to estimate forecasted VR/AR units in 2016-2020 for these three groups, we applied the KZero percentages to forecasts provided by ABIresearch for total VR and AR units, and assumed the 2018 percentages would hold for 2019-2020. As shown in Table 1, we estimate low adoption will represent 18.5 million units sold in 2016-2020, medium adoption will represent 68.5 million units,¹¹ and high adoption will represent 160 million units.

Table 1
Projections of VR/AR Units Shipped (MM)
2016 – 2020

| Year | Low Adoption | Medium Adoption | High Adoption |
|--------------|---------------------|------------------------|----------------------|
| 2016 | 1.2 | 4.4 | 8.4 |
| 2017 | 2.0 | 7.3 | 16.4 |
| 2018 | 3.1 | 11.6 | 27.7 |
| 2019 | 4.9 | 18.1 | 43.1 |
| 2020 | 7.3 | 27.1 | 64.4 |
| Total | 18.5 | 68.5 | 159.9 |

Notes:

[1] Projected units include ABIresearch estimates for VR Standalone, VR Mobile, VR Tether, and AR Smart Glasses.

[2] Projected units for Low Adoption and Medium Adoption are calculated by taking the High Adoption projected units and multiplying by the corresponding KZero percentage for each year. Percentages for 2019 and 2020 are assumed to be the same as 2018. It is also assumed that the percentages for VR are the same for AR.

Sources:

ABIresearch, "Gaming, Augmented, and Virtual Reality Market Data Release," Q3, 2015; KZero Worldwide, "VR Market Sizing," at Slide 11, available at: <http://www.kzero.co.uk/blog/consumer-virtual-reality-market-worth-13bn-2018/>.

¹⁰ KZero Worldwide, "VR Market Sizing," at Slides 7 and 11; <http://www.ondigitalmarketing.com/learn/odm/foundations/diffusion-of-innovation/>; <http://www.ondigitalmarketing.com/learn/odm/foundations/5-customer-segments-technology-adoption/>.

¹¹ 68.5 million units for medium adoption is comparable in size to ABIresearch’s gaming and entertainment industry projections for VR/AR totaling 71.9 million. ABIresearch, "Gaming, Augmented, and Virtual Reality Market Data Release," Q3, 2015.

We then use our VR/AR forecasts based on the above low, medium, and high adoption scenarios in two complementary approaches to estimate the economic impacts associated with VR/AR. In the first approach, we develop a conservative baseline that assumes that the only economic impact associated with VR/AR are the funds that consumers are forecasted to spend on VR/AR headsets over the next five years. This is conservative in that it does not account for the associated ecosystem that could develop around VR/AR, such as accessories and VR/AR applications, or the innovations that build on VR/AR and that cannot be easily predicted today. Using this approach, we forecast that global VR/AR revenues for 2016 to 2020 will total approximately \$2.8 billion for low adoption, \$10.3 billion for medium adoption, and \$24.0 billion for high adoption.¹²

In the second approach, we utilize past introductions of similar technologies to help inform the likely impacts of VR/AR. In particular, we view smartphones and tablets as sufficiently similar technologies to VR/AR to allow us to use an estimate of their economic impacts to infer the potential economic effects associated with VR/AR. Although clear differences exist between smartphones and tablets, and initial adoption of these devices far exceeded what is projected for VR/AR in the first five years, the expected uses of the devices and the ecosystems they would create are expected to be similar: for example, their use (1) for entertainment, such as gaming, as well as viewing television programs and movies, (2) for communication with co-workers, friends, and family, and (3) by professionals for example in the education, healthcare, and retail sectors.

Moreover, similar to smartphones and tablets, VR/AR is also expected to emerge as a platform for a myriad of applications, advertising, and commerce opportunities. Given how innovative VR/AR technology is, new apps will need to be designed and developed from the ground up,¹³ much like they have been for smartphones. In this regard, Digi-Capital predicts that AR's "addressable market is similar to today's smartphone/tablet market" and "could open up a similar software and services economy to today's mobile market."¹⁴ And, VR has the potential to create truly innovative, immersive content experiences that have not been experienced before. Blending VR with AR through augmentation with haptic technology opens up even more potential. According to industry analysts, VR/AR is "the next technology megatrend, the next evolution of computing, and ... has the potential to be as profound a technology platform as the smartphone today."¹⁵

¹² We estimate the combined effect of VR and AR since both share many similarities with smartphones and tablets, and because VR and AR have significant economic potential. However, AR headsets currently primarily serve the enterprise market, making AR projections more uncertain due to the difficulty of predicting large enterprise contracts. If AR headsets are excluded from our conservative approach, we forecast that global VR revenues for 2016 to 2020 will total approximately \$1.9 billion for low adoption, \$6.9 billion for medium adoption, and \$16.1 billion for high adoption.

¹³ See <http://www.ft.com/intl/cms/s/2/dae861ee-b275-11e5-b147-e5e5bba42e51.html>.

¹⁴ For VR, Digi-Capital predicts an addressable market of primarily core games and 3D files plus niche enterprise users with "consumer software and services economics similar to current games, films, and theme parks." See <http://fortune.com/2015/04/25/augmented-reality-virtual-reality/>.

¹⁵ See <http://www.foxbusiness.com/technology/2015/06/11/why-virtual-reality-will-be-bigger-than-smartphones/>, citing Piper Jaffray analyst Gene Muster and Barron's Tiernan Ray.

In using smartphones and tablets to help inform the likely impacts of VR/AR, we first develop an econometric approach to estimate the relationship between GDP levels and smartphone and tablet sales, while controlling for other macroeconomic factors that also affect GDP. Using this estimated relationship between GDP and smartphone and tablet sales, along with data on smartphone and tablet ownership costs, we then estimate the multiplier associated with the average cost to a consumer of acquiring and using a smartphone or tablet over its life, relative to the average impact of a smartphone or tablet on GDP. This multiplier captures the additional GDP impact of smartphones and tablets over and above what consumers spend to own those devices. This additional GDP impact represents the economic activity associated with the ecosystem that has developed around smartphones and tablets, including, for example, applications development, accessories, and productivity enhancements, and does not include money spent to purchase devices and pay for monthly phone and data plans.

We find that the impact of an additional smartphone or tablet on GDP represents a multiplier of approximately 4.3 times the cost to the consumer of owning the device. In other words, for every \$100 spent on a device, an additional \$430 of total GDP benefit is generated. We can then apply this multiplier to projected VR/AR headset revenues for 2016-2020, effectively scaling the per-unit economic impact of a smartphone or tablet to the projected size of the VR/AR market in the next five years. This yields an additional estimated global economic impact of VR/AR ranging from \$11.8 billion for low adoption, to \$43.7 billion for medium adoption, to \$102.0 billion for high adoption in the 2016-2020 time period. Thus, we estimate the total economic potential of VR/AR technology over the next five years could be \$14.6 billion for low adoption, representing the addition of \$2.8 billion in headset revenues and \$11.8 billion in additional multiplier effect capturing related ecosystems of economic activity. This total economic potential could reach \$54.0 billion for medium adoption or could be up to \$126.0 billion for high adoption. Our results are summarized below in Table 2.¹⁶

¹⁶ If AR headsets are excluded from our comparable approach, we estimate that for VR, the additional economic impact for 2016 to 2020 will total approximately \$7.9 billion for low adoption, \$29.4 billion for medium adoption, and \$68.5 billion for high adoption. Thus, we estimate the total economic potential of VR technology over the next five years could be \$9.8 billion for low adoption, representing the addition of \$1.9 billion in headset revenues and \$7.9 billion in additional multiplier effect capturing related ecosystems of economic activity. This total economic potential could reach \$36.3 billion for medium adoption or could be up to \$84.6 billion for high adoption.

Table 2
Estimated Economic Impact of VR/AR Technology (\$B)
2016 – 2020

| | Low Adoption | Medium Adoption | High Adoption |
|--|---------------------|------------------------|----------------------|
| [1] Conservative Approach (\$B) | \$2.8 | \$10.3 | \$24.0 |
| [2] Comparable Approach (\$B) | \$11.8 | \$43.7 | \$102.0 |
| [3] Estimated Total Economic Impact (\$B) | \$14.6 | \$54.0 | \$126.0 |

Notes:

[1] From Table 3.

[2] From Table 6.

[3] = [1] + [2].

Sources:

Table 3; Table 6.

It is important to note that we have estimated the effect of VR/AR on the economy, as measured by GDP. However, the impact of VR will extend beyond the economy, with experts predicting a range of social benefits. For example, research has found that immersive virtual reality experiences have been shown to engender racial sensitivity, greater empathy for those with disabilities, respect for the environment, and an increased willingness to help others.¹⁷ Research also shows VR can effectively convey health messages by showing people the effect of poor health choices on their future selves.¹⁸ AR has also been shown to have social benefits, for example in education through learning gains, increased student motivation, and facilitating interaction and collaboration.¹⁹ Some of these social impacts will have economic consequences, which may be accounted for in our estimates. For instance, if experiential education through AR leads to increased student engagement and, thus, more qualified and productive workers, we may pick up on this effect in our economic impact estimates. However, there are also benefits to individuals and society that are not accounted for in our models, both tangible and intangible. We leave the estimation of these effects to future research.

In what follows, we describe our methodology for estimating the potential economic impacts of VR/AR in detail in Section II. Using this methodology, we then discuss a range of potential economic impacts in Section III.

II. Methodological Approach

In estimating the potential economic effects associated with a relatively new technology such as VR/AR, it is important to recognize the difficulty associated with accurately

¹⁷ See <http://www.fastcoexist.com/3041200/could-virtual-reality-make-us-better-people>.

¹⁸ *Id.*

¹⁹ Bacca, J., Baldiris, S., Fabregat, R., Graf, S., & Kinshuk. (2014). "Augmented Reality Trends in Education: A Systematic Review of Research and Applications." *Educational Technology & Society*, 17 (4), 133–149.

predicting its future economic impacts. This stems from the fact that it is challenging to predict, *a priori*, the areas in which VR/AR will be used, the extent of adoption of VR/AR, the technologies that will be developed that build upon VR/AR, and the associated economic impacts.

This is highlighted by the illustrative example of the history of moving pictures, in which numerous developments occurred that could not have been predicted at the outset. When film was first introduced in the late 1800s, it represented a new, innovative medium for recording and distributing content to consumers.²⁰ Before moving pictures, the only way to experience places, events, and entertainment beyond photographs, static pictorial renderings, or written and verbal descriptions, was by being present and viewing live. With the advent of film, a range of content, from news to motion pictures, became accessible as moving pictures at designated times in designated places (i.e., theaters).²¹ Subsequent innovation in the moving picture industry experienced varying degrees of success with the most successful building upon prior innovations and leading to the development of related ecosystems.

Decades after the invention of moving pictures, the introduction of the television, a very successful innovation, made moving picture content even more accessible to individual consumers by bringing it into their homes. Televisions allowed for a range of content to be broadcast simultaneously, still at designated times, giving consumers more viewing options in the comfort of their own homes.²² An ecosystem related to television developed that included the manufacture of televisions, television production studios, and television advertising.²³

Following television, the next phase in the evolution of moving pictures content was recorded video distribution, first through video cassettes and later DVDs, along with their related playback machines.²⁴ These devices relaxed the time constraint on consuming video content by allowing consumers to view what they wanted, when they wanted. Along the way, the viewing experience was continually enhanced by advances in resolution (i.e., high definition) and display technology.²⁵ On-demand viewing was even further enhanced by the innovation of on-demand streaming, which significantly diminished the importance of playback machines, video cassettes, DVDs, and live television shows.²⁶

²⁰ See <http://www.britannica.com/art/history-of-the-motion-picture>.

²¹ See <http://www.britannica.com/art/history-of-the-motion-picture>;
http://www.clpgh.org/exhibit/neighborhoods/downtown/down_n71.html.

²² See <http://www.britannica.com/art/history-of-the-motion-picture/The-war-years-and-post-World-War-II-trends#toc284132>.

²³ See <http://www.emmytvlegends.org/resources/tv-history>;
<http://www.nytimes.com/1995/07/18/us/last-us-tv-maker-will-sell-control-to-koreans.html>;
<http://www.detroitnews.com/story/opinion/2014/10/22/americans-make-tvs/17680951/>;
http://www.historyoftelevision.net/history_tv_ads.html.

²⁴ See <http://www.aes.org/aeshc/docs/recording.technology.history/notes.html>;
https://transition.fcc.gov/omd/history/tv/documents/76years_tv.pdf.

²⁵ See <http://blogs.reuters.com/data-dive/2014/12/17/a-very-brief-history-of-television-displays/>.

²⁶ See <http://www.washingtonpost.com/wp-dyn/content/article/2005/06/14/AR2005061401794.html>;
<http://www.forbes.com/sites/dadehayes/2013/07/08/six-reasons-why-dvds-still-make-money-and-wont->

At present, mobile viewing is a quickly growing medium for viewing content.²⁷ This innovation allows viewers to watch moving picture content wherever they happen to be. An ecosystem that includes smartphone and tablet manufacturing, providing wireless internet connections, and mobile applications and ads has developed as part of the popularity of mobile devices.²⁸ The evolution of moving pictures has thus evolved from viewing content at set times and set locations to on-demand viewing anywhere. Critically, the innovation of mobile viewing was built upon previous innovations such as television and recorded videos. VR/AR technology could be poised to become the next successful wave in this history of technological innovation. According to the *Financial Times*, VR “could become as big as cinema and television,”²⁹ thus potentially claiming its place as the next phase in the way consumers consume innovative content including video entertainment.

The example of motion pictures discussed above illustrates the unpredictable path of innovation. Given the challenges associated with predicting the future of a given innovation, we take two complementary approaches in estimating the potential economic impacts of VR/AR over the next five years.

a. *Conservative (Sales-Based) Approach*

In the first, which we term the “conservative approach,” we predict the economic impact of VR/AR technology by estimating the size of the VR/AR headset marketplace. To do so, we estimate the revenue that these products will generate over the next five years by relying on two sources of data: projected sales shipments of VR/AR headsets and the expected average selling price of these headsets. The sales shipment forecast data are provided by ABIresearch³⁰ and adjusted by KZero estimates to arrive at forecasts for three potential adoption scenarios: low adoption representing 18.5 million headsets shipped between 2016 and 2020; medium adoption representing 68.5 million headsets, or high adoption

die-anytime-soon/; <http://www.businessinsider.com/online-streaming-is-making-the-dvd-obsolete-2013-1>; <http://www.theguardian.com/media-network/2015/feb/05/netflix-subscription-services-television-ad-revenues>.

²⁷ See http://www.nytimes.com/2012/02/09/business/media/young-people-are-watching-but-less-often-on-tv.html?_r=0; <http://www.ericsson.com/res/docs/2015/consumerlab/ericsson-consumerlab-tv-media-2015.pdf>; <http://www.forbes.com/sites/markhughes/2015/03/21/the-millennial-trends-that-are-killing-cable/>.

²⁸ See http://www2.deloitte.com/content/dam/Deloitte/se/Documents/technology-media-telecommunications/Digital-Democracy-Survey-DDS_Executive_Summary_Report_Final_2015-04-20-tmt.pdf; <http://www.gartner.com/newsroom/id/2939217>; http://www.pewinternet.org/files/2015/03/PI_Smartphones_0401151.pdf; <http://www.businessinsider.com/mobile-web-vs-app-usage-statistics-2014-4>; <http://www.businessinsider.com/mobile-video-advertising-growth-2015-5>.

²⁹ See <http://www.ft.com/intl/cms/s/0/b29a3106-9761-11e5-9228-87e603d47bdc.html>.

³⁰ ABIresearch’s VR estimates are based on conversations with companies, early sales for released models and developer kits, planned released dates, and industry knowledge. Their AR estimates are also based on conversations with potential enterprise customers.

representing 160 million headsets.³¹ Average selling prices for VR headsets are obtained from KZero,³² and are estimated to be \$150.³³ It is important to note that this approach is likely to be conservative because it assumes a lower sales price for VR/AR headsets than is currently observed (which reduces our economic impact results),³⁴ strictly includes the sales of headsets and excludes all revenues that could be gained through sales of peripheral products (e.g., computers, software, and input systems), and it excludes related applications and innovations that build upon VR/AR.

b. *Comparable (Econometric) Approach*

In the second approach, which we term the “comparable approach,” we utilize past introductions of similar technologies to help inform the likely impacts of VR/AR. In particular, as discussed above, we view smartphones and tablets as sufficiently similar technologies to VR/AR, and use estimates of the economic impacts of smartphones and tablets to predict the potential economic effects associated with VR/AR.

We believe that the use of smartphones and tablets as a proxy for VR and AR technology is a reasonable comparison based on the way both of these technologies are used and relied upon. The iPhone and iPad were first released in 2007 and 2010, respectively;³⁵ today, users of these devices can keep all of their contacts in one place, navigate using GPS functionality, communicate over voice, text, email, and video, read documents electronically, take pictures, record videos, surf the internet, watch movies and television programs, listen to music, connect via social media, and play games. Additionally, tablets provide more computing power and a larger screen,³⁶ which, for example, lends tablets to more popular use for entertainment and productivity related tasks.³⁷

³¹ See Table 3. ABIresearch defines AR and VR as “AR and VR differ primarily in their screen usage; AR overlays info on top of natural vision with pass-through technology, while VR completely obscures a user's vision with display.” ABIresearch, “Gaming, Augmented, and Virtual Reality Market Data Release,” Q3, 2015.

³² KZero defines a virtual reality device as “a piece of hardware resembling goggles. A user places this unit on their head and sees a digital image on a display as opposed to seeing the real-world around them.” KZero Worldwide, “Consumer Virtual Reality State of the Market Report,” March 2014, Version 1.2, at Slide 2.

³³ KZero Worldwide, “VR Market Sizing,” at Slide 17.

³⁴ The \$150 average selling price we use only represents VR headsets. AR headsets are currently primarily targeted for the enterprise market at much higher price points, for example around \$2,000 (based on conversations with ABIresearch). Thus, the economic impact of AR based on the conservative approach may be even higher than we estimate due to higher average selling prices.

³⁵ The iPhone and iPad are both considered to be the first of their kind, and have led to the development of many similar devices. See <http://www.nytimes.com/2007/06/27/technology/circuits/27pogue.html>; <http://www.nytimes.com/2010/04/04/technology/04ipad.html>.

³⁶ See <http://www.pcworld.com/article/2602917/laptop-vs-tablets-how-they-compare-for-true-productivity.html>.

³⁷ Even though tablets lack the ability to make phone calls, most have more processing power and therefore more functionality with other programs. See http://www.pcworld.com/article/247387/5_ways_tablets_are_better_than_laptops_or_smartphones.html; https://www.catalystmr.com/wp-content/uploads/2010/11/iPad_Effect_Mag_merged_1110.pdf; <http://techcrunch.com/2011/02/12/10-reasons-to-buy-a-tablet-and-5-reasons-not-to/>.

Smartphones and tablets are now indispensable to many industries and have increased productivity of the global economy.³⁸ For example, smartphones and tablets have enabled near instantaneous communication that has become the expectation for those conducting business. These devices allow employees to stay connected by email, text, voice, and video while giving them the ability to work on-the-go.³⁹ Currently, healthcare professionals use smartphones and tablets to access health records, communicate and consult with patients, access textbooks, guidelines and medical literature, and track vital signs of patients.⁴⁰ Smartphones and tablets have also become an important part of the education system, allowing students to access virtual textbooks, participate in learning labs, and create their own personalized learning environments.⁴¹

VR/AR is likely to be the next major technological development in line with its smartphone and tablet predecessors. This technology has promising applications in the same industries as smartphones and tablets, and eventually may surpass the economic contributions of smartphones and tablets.⁴² Some industry insiders, such as Oculus founder Palmer Lucky, believe that VR/AR “could replace smartphones for mainstream users” in the future, “becoming the tech industry’s dominant computing platform.”⁴³ In addition to enhancing smartphone capabilities such as navigation, communication, and entertainment, VR will create opportunities for new experiences such as virtual meetings and conferences,⁴⁴ doctors simulating risky surgeries prior to operating,⁴⁵ and allowing for the interactions of virtual classmates.⁴⁶ Similarly, AR also has practical applications for the future, including heads up displays in vehicles and the ability to turn blueprints to life before committing to the manufacturing process.⁴⁷ Education professionals also hope that VR/AR can be adapted to the classroom, allowing kids to take tours of museums and places that are not financially accessible, or to experience phenomena in 3-D to help conceptualize abstract concepts.⁴⁸ Ultimately, these advances in technology draw strong comparisons to the benefits that smartphones and tablets currently provide, making them a good proxy for what VR/AR can contribute economically.

³⁸ See Williams, Chris, Gabriel Solomon, and Robert Pepper, “What is the impact of mobile telephony on economic growth?” Deloitte, GSMA, and Cisco, November 2012.

³⁹ See

<http://www.business2community.com/mobileapps/rolesmartphonesbusinesses01012882#oAmwAETjFWLae6Xy.97>.

⁴⁰ See <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4029126/>.

⁴¹ See <http://www.edweek.org/dd/articles/2013/02/06/02reading.h06.html>.

⁴² See <http://techcrunch.com/2015/04/06/augmented-and-virtual-reality-to-hit-150-billion-by-2020/#.zowrkeu:R0vA>.

⁴³ See <http://www.ft.com/intl/cms/s/2/dae861ee-b275-11e5-b147-e5e5bba42e51.html>.

⁴⁴ AltspaceVR is creating software that allows businesses to host meetings with virtual avatars. The app tracks head movements to allow for more nonverbal communication, which cannot be captured while talking on the phone. See <http://www.latimes.com/business/lafivirtualreality20150109story.html>.

⁴⁵ See <http://www.livescience.com/44384-oculus-rift-virtual-reality-uses-beyond-gaming.html>.

⁴⁶ See <http://www.ign.com/articles/2015/12/09/9-things-virtual-reality-r-will-change-other-than-games>.

⁴⁷ See http://www.huffingtonpost.com/brandon-gorrell/chevy-someday-augmented-reality_b_4137851.html; <http://www.techrepublic.com/article/microsoft-hololens-what-does-it-mean-for-business/>.

⁴⁸ See <http://www.vrs.org.uk/virtualrealityeducation/>;

<http://www.usatoday.com/story/tech/2015/09/28/google-rolls-out-virtual-reality-field-trips/72825732/>.

A portion of the economic impact of smartphones and tablets is associated with the broader ecosystem related to these devices.⁴⁹ For example, there are millions of developers registered in the Apple database for applications, which allows for innovation and creation on a large scale. On the Apple App Store alone, there were an estimated 1.2 million apps and 75 billion downloads as of June 2014.⁵⁰ The success of VR/AR will be just as dependent on the applications and media that will be created for these products and will rely on developers to make content that can take advantage of the hardware provided by manufacturers. This application ecosystem represents significant economic impacts associated with smartphones and tablets, and a similar ecosystem has the potential to contribute substantial economic impacts as a result of VR/AR technology.⁵¹

In using smartphones and tablets to help inform the likely impacts of VR/AR, we first develop a robust, econometric approach to estimate the relationship between GDP levels and smartphone and tablet sales, while controlling for other macroeconomic factors that also affect GDP. The factors for which we control are closely related to the controls from a seminal economic growth paper published by Robert Barro in May 1991.⁵² In it, Barro analyzes how GDP per capita growth in a cross section of countries is explained by a set of macroeconomic indicators, including education, fertility and mortality rates, government consumption, infrastructure investment, market distortions, and political instability.⁵³ Our fully specified model is also informed by two additional papers that incorporate broadband use and patent applications to account for the effects of a country's broadband infrastructure and technological innovation on GDP.⁵⁴ The fully specified GDP model, which is estimated at the country- and year-level, is structured as:⁵⁵

⁴⁹ See <http://www.eweek.com/c/a/Mobile-and-Wireless/Smartphone-Market-Success-or-Failure-10-Critical-Factors-498307>; <http://www.businessinsider.com/mobile-video-advertising-growth-2015-5>; <http://www.wsj.com/articles/SB10001424127887323551004578441130657837720>; <http://www.technet.org/wp-content/uploads/2012/02/TechNet-App-Economy-Jobs-Study.pdf>.

⁵⁰ See <http://techcrunch.com/2014/06/02/itunes-app-store-now-has-1-2-million-apps-has-seen-75-billion-downloads-to-date/>.

⁵¹ AR is currently primarily focused on the enterprise market, which may have potential for even larger economic effects, for example due to substantial investment in enterprise applications relative to enterprise-related investments associated with smartphones and tablets. To the extent this is the case, our comparable approach AR estimates may be understated.

⁵² Our model produced similar results to Barro's in terms of the direction of coefficients. For example, we both found positive coefficients for both primary and secondary education enrollment and negative coefficients for government expenditures and inflation. Barro, Robert, "Economic Growth in a Cross Section of Countries," *The Quarterly Journal of Economics*, 106(2), May 1991, pp. 407-443.

⁵³ Barro also includes a variable that measures the initial level of GDP because his dependent variable is GDP growth per capita, which was not relevant for our GDP model.

⁵⁴ See Czernich, Nina, Oliver Falck, Tobias Kretschmer, and Ludger Woessmann. "Broadband Infrastructure and Economic Growth." *The Economic Journal* 505-530 (2011); Ulku, Hulya, "R&D, Innovation, and Economic Growth: An Empirical Analysis," *IMF Working Paper*, September 2004.

⁵⁵ Although Barro (1991) used GDP growth as the dependent variable, we use GDP levels for ease of interpretation of our results.

$$Y_{GDP_{t,c}} = \alpha + \beta_1 X_{SMART-TAB_{t,c}} + \beta_2 X_{PRIM_{t,c}} + \beta_3 X_{SECOND_{t,c}} + \beta_4 X_{FERTM_{t,c}} + \beta_5 X_{GOV-EX_{t,c}} + \beta_6 X_{CAP-FORM_{t,c}} + \beta_7 X_{CPI_{t,c}} + \beta_8 X_{RULELAW_{t,c}} + \beta_9 X_{TOT-POP_{t,c}} + \beta_{10} X_{PATENT_{t,c}} + \beta_{11} X_{BBAND_{t,c}} + D_t + D_c + \varepsilon$$

where:⁵⁶

- $Y_{GDP_{t,c}}$ is a country's GDP in year t in country c, converted to millions of constant 2014 international dollars using purchasing power parity rates.⁵⁷
- $X_{SMART-TAB_{t,c}}$ is the number, in millions, of smartphone and tablet units shipped in year t in country c.⁵⁸
- $X_{PRIM_{t,c}}$ is the ratio of the total number of students enrolled in primary education over the total official primary education age population in year t in country c,⁵⁹ which is expected to positively affect GDP through a more educated workforce, leading to productivity gains.
- $X_{SECOND_{t,c}}$ is the ratio of the total number of students enrolled in secondary education over the total official secondary education age population in year t in country c,⁶⁰ is expected to positively affect GDP for the same reasons as $X_{PRIM_{t,c}}$.
- $X_{FERTM_{t,c}}$ is the number of births that survive to the age of 5 per woman in year t in country c,⁶¹ which is expected to negatively affect GDP because of an inverse relationship between human capital and fertility; that is, as potential parents' time becomes more valuable in line with increased human capital development, it increases the cost of raising children thereby reducing fertility.

⁵⁶ Explanations of the expected relationship of each variable with GDP are based on Barro(1991), Ulku(2004), and Czernich et al.(2011).

⁵⁷ This variable is calculated by converting annual GDP in local currency for each country to 2014 local currency, and then converting that into international dollars using purchasing power parity rates for each country in 2014. The following World Bank variables were used in this calculation:

<http://data.worldbank.org/indicator/NY.GDP.MKTP.KN>;

<http://data.worldbank.org/indicator/NY.GDP.MKTP.CN>; <http://data.worldbank.org/indicator/PA.NUS.PPP>.

⁵⁸ Strategy Analytics defines smartphones as "a data-centric, cellular handset or cellular PDA with a branded, high-level operating system. The OS is open to third-party applications, encourages data-centric activities, and is typically capable of multi-tasking... The size of the smartphone should be pocketable." See Strategy Analytics, "Global Smartphone Sales Forecast For 88 Countries: 2007 to 2020," March 2014. Strategy Analytics defines tablets as, "The Tablet category refers to a mobile or portable computing device wherein all components are contained within a slate-shaped form factor with a touchscreen (operated by finger or stylus) color display. Screen sizes are split among 6 distinct ranges: 6.9" or less, 7" - 7.9", 8" - 8.9", 9" - 9.9", 10" - 10.9", and 11" or more." See Strategy Analytics, "Q3 2015: Tablet Operating System Forecast - Shipments, Installed Base & by Price Tier 2010 - 2019," August 2015.

⁵⁹ See <http://data.worldbank.org/indicator/SE.PRM.ENRR>.

⁶⁰ See <http://data.worldbank.org/indicator/SE.SEC.ENRR>.

⁶¹ $X_{FERTM_{t,c}}$ is calculated using 2 variables: Fertility Rate and Mortality Rate Under 5 (per 1,000 births). The number of births that survive to age 5 per woman = Fertility Rate * [1 - (Mortality Rate Under 5 / 1,000)]. This is similar to Barro's calculation. See Barro, Robert, "Economic Growth in a Cross Section of Countries," *The Quarterly Journal of Economics*, 106(2), May 1991, pp. 407-443, at pp. 423-424. See also, <http://data.worldbank.org/indicator/SP.DYN.TFRT.IN>; <http://data.worldbank.org/indicator/SH.DYN.MORT>.

- $X_{GOV-EX_{t,c}}$ is the general government final consumption expenditure as a percent of GDP in year t in country c,⁶² which is expected to negatively affect GDP due to distorting effects from taxation or government expenditure programs.
- $X_{CAP-FORM_{t,c}}$ is the gross capital formation as a percent of GDP in year t in country c,⁶³ which represents infrastructure investment and is expected to positively affect GDP through increased economic activity related to such investment.
- $X_{CPI_{t,c}}$ is inflation as measured by the consumer price index in year t in country c,⁶⁴ which is expected to negatively affect GDP by discouraging investment.
- $X_{RULELAW_{t,c}}$ is a worldwide governance indicator for the rule of law measuring the extent to which agents have confidence in and abide by the rules of society in year t in country c,⁶⁵ which is expected to positively affect GDP because confidence in institutions such as property rights should encourage investment.
- $X_{TOT-POP_{t,c}}$ is the total population of a country in millions in year t in country c,⁶⁶ which is expected to positively affect GDP as more people can engage in economic activity.
- $X_{PATENT_{t,c}}$ is the sum of resident and non-resident patent applications per capita in year t in country c,⁶⁷ which is expected to positively affect GDP as a proxy for innovation.
- $X_{BBAND_{t,c}}$ is the number of fixed broadband subscriptions per 100 people in year t in country c,⁶⁸ which is expected to positively affect GDP through facilitation of information dissemination and innovation.
- D_t and D_c are year t and country c dummy variables, respectively, representing year and country fixed effects.

To test the robustness of our model, we built up to this full specification by first regressing $Y_{GDP_{t,c}}$ on only $X_{SMART-TAB_{t,c}}$ and the year and country fixed effects. Next, we added the control variables from Barro(1991), followed by the addition of $X_{PATENT_{t,c}}$ based on

⁶² The World Bank defines general government final consumption expenditure as including “all government current expenditures for purchases of goods and services (including compensation of employees). It also includes most expenditures on national defense and security, but excludes government military expenditures that are part of government capital formation.” See <http://data.worldbank.org/indicator/NE.CON.GOVV.ZS>.

⁶³ The World Bank defines Gross Capital Formation as “Gross capital formation (formerly gross domestic investment) consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories. Fixed assets include land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. Inventories are stocks of goods held by firms to meet temporary or unexpected fluctuations in production or sales, and ‘work in progress.’” See <http://data.worldbank.org/indicator/NE.GDI.TOTL.ZS>.

⁶⁴ See <http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG>.

⁶⁵ This variable “Reflects 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.” See <http://info.worldbank.org/governance/wgi/pdf/rl.pdf>.

⁶⁶ See <http://data.worldbank.org/indicator/SP.POP.TOTL>.

⁶⁷ See <http://data.worldbank.org/indicator/IP.PAT.RESD>; <http://data.worldbank.org/indicator/IP.PAT.NRES>.

⁶⁸ See <http://data.worldbank.org/indicator/IT.NET.BBND.P2>.

Ulku(2004), and then the addition of $X_{BBAND_{t,c}}$ based on Czernich et al. (2011). Smartphone and tablet units remain positive and statistically significant in each specification.

The data used in our regressions are obtained from the World Bank and Strategy Analytics. Specifically, we use two datasets from the World Bank, the World Development Indicators and World Governance Indicators, and smartphone and tablet unit shipment data from Strategy Analytics.⁶⁹ The data included in the models cover the 2007-2013 time period for 63 countries.⁷⁰

The results from our econometric models are then used to predict the global economic impacts of VR/AR for the 2016-2020 time period. To do so, we use the estimated relationship between GDP and smartphone and tablet sales, along with data on smartphone and tablet ownership costs, to estimate the multiplier associated with the average cost to a consumer of acquiring and using a smartphone or tablet over its life relative to the average GDP impact of a smartphone or tablet on GDP. With this smartphone/tablet multiplier and VR/AR revenue forecasts, we are able to estimate a range of global GDP impacts of VR/AR for the 2016-2020 time period.

III. Findings

Based on the two methodological approaches described above, we estimated both a “conservative approach” and “comparable approach” for VR/AR’s potential economic impact on the global economy for 2016-2020. As described above, the conservative approach estimates the revenues from the sales of headsets, whereas the comparable approach estimates the larger additional impact VR/AR may have by spurring the production of additional peripheral products and innovations, and potentially leading to increased workplace productivity. Below, we discuss the results of the two approaches.

a. *Conservative (Sales-Based) Approach*

In order to calculate the headset revenues associated with the conservative approach, we use unit projections developed by ABIresearch⁷¹ and adjusted by KZero estimates to arrive at forecasts for three potential adoption scenarios: low, medium, and high adoption. We

⁶⁹ The variables from the World Indicator Dataset includes: $Y_{GDP_{t,c}}$, $X_{BBAND_{t,c}}$, $X_{PATENT_{t,c}}$, $X_{PRIM_{t,c}}$, $X_{SECOND_{t,c}}$, $X_{FERTM_{t,c}}$, $X_{GOV-EX_{t,c}}$, $X_{CAP-FORM_{t,c}}$, $X_{CPI_{t,c}}$, and $X_{TOT-POP_{t,c}}$. The variable from the World Governance Indicators is $X_{RULELAW_{t,c}}$. $X_{SMART-TAB_{t,c}}$ is from both Strategy Analytics datasets.

⁷⁰ The data were limited to 2007 – 2013 because 2007 was the first year that Strategy Analytics reported smartphone data, and 2013 is the last year of data availability for several variables. The following 63 countries with a complete set of data are included in the model: Algeria, Australia, Austria, Bangladesh, Belarus, Belgium, Bulgaria, Canada, Chile, China, Colombia, Croatia, Czech Republic, Denmark, Ecuador, Egypt Arab Rep., Estonia, Finland, France, Georgia, Germany, Greece, Hungary, India, Indonesia, Iran Islamic Rep., Ireland, Israel, Italy, Japan, Kenya, Korea Rep., Latvia, Lithuania, Macedonia FYR, Mexico, Moldova, Morocco, Netherlands, Norway, Pakistan, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Saudi Arabia, Serbia, Slovak Republic, Slovenia, South Africa, Spain, Sudan, Sweden, Thailand, Turkey, Ukraine, United Kingdom, United States, Uruguay, and Venezuela.

also use the expected average selling price for headsets of \$150 from KZero. (In using this estimate of \$150 for average selling price, it is important to note that this represents the average price that is expected to be observed over the 2016 to 2018 time period for *all* VR/AR devices on the market. We view this estimate to be reasonable because (1) although devices such as Oculus Rift (\$599) are currently for sale in the marketplace, other less expensive devices such as Oculus Gear VR (\$99) and Google Cardboard (with a price as low as \$19.99) are also currently available, and (2) prices for consumer electronics tend to decrease over time. Finally, it is also worth noting that to the extent we use a lower price for VR/AR than is ultimately observed, our economic impact estimates will be conservative since we multiply projected sale prices by unit sale forecasts to arrive at our economic impact estimates.⁷²)

Table 3 below provides the results of this method and shows that global VR/AR revenues for 2016 to 2020 will total approximately \$2.8 billion for low adoption, \$10.3 billion for medium adoption, and \$24.0 billion for high adoption.⁷³

Table 3
Conservative Approach
Estimated Economic Impact of VR/AR Technology (\$B)
2016 – 2020

| Year | Low Adoption | Medium Adoption | High Adoption |
|--------------|---------------------|------------------------|----------------------|
| 2016 | \$0.2 | \$0.7 | \$1.3 |
| 2017 | \$0.3 | \$1.1 | \$2.5 |
| 2018 | \$0.5 | \$1.7 | \$4.1 |
| 2019 | \$0.7 | \$2.7 | \$6.5 |
| 2020 | \$1.1 | \$4.1 | \$9.7 |
| Total | \$2.8 | \$10.3 | \$24.0 |

Note:

[1] Estimated Revenue = \$150 * Projected Units from Table 1. \$150 is the average estimated unit cost for 2016 - 2018 from KZero. It is assumed that average price will not change after this period.

Sources:

Table 1; KZero Worldwide, "VR Market Sizing," at Slide 17, available at: <http://www.kzero.co.uk/blog/consumer-virtual-reality-market-worth-13bn-2018/>.

⁷¹ ABIresearch's VR estimates are based on conversations with companies, early sales for released models and developer kits, planned released dates, and industry knowledge. Their AR estimates are also based on conversations with potential enterprise customers.

⁷² The \$150 average selling price we use only represents VR headsets. AR headsets are currently primarily targeted for the enterprise market at much higher price points, for example around \$2,000 (based on conversations with ABIresearch). Thus, our economic impact estimates for AR are even more conservative.

⁷³ If AR headsets are excluded from our conservative approach, we forecast that global VR revenues for 2016 to 2020 will total approximately \$1.9 billion for low adoption, \$6.9 billion for medium adoption, and \$16.1 billion for high adoption.

b. *Comparable (Econometric) Approach*

The regression results from the comparable approach where we estimate the effect of smartphones and tablets on GDP can be found below in Table 4. Generally, we find the expected signs on the coefficients in our regression models. For example, larger numbers of broadband subscribers are associated with higher GDP levels, and increased inflation is associated with lower GDP levels.

Table 4
Comparable Approach
Dependent Variable: GDP
2007 – 2013

| Independent Variables | (1) | (2) | (3) | (4) |
|---|---------------|---------------|---------------|---------------|
| Smartphone + Tablet Units Shipped (MM) | 14,370 *** | 11,737 *** | 11,782 *** | 11,262 *** |
| Enrolled in Primary Schooling (%) | - | 2,329 | 4,277 | 7,926 |
| Enrolled in Secondary Schooling (%) | - | 4,707 | 5,221 | 4,692 |
| Fertility Rate Adjusted for Child Mortality | - | 560,483 | 656,580 | 518,703 |
| Government Expenditure (% GDP) | - | (14,408) | (19,783) | (10,349) |
| Gross Capital Formation (% GDP) | - | 5,947 | 6,734 | 9,211 |
| Inflation, Consumer Prices (%) | - | (2,615) | (2,847) | (3,141) |
| Rule of Law Index | - | 178,640 * | 162,580 * | 188,500 ** |
| Total Population (MM) | - | 28,528 *** | 28,952 *** | 27,849 *** |
| Patent Applications per Capita | - | - | (20,686,010) | 42,178,820 |
| Broadband Subscribers per 100 People | - | - | - | 14,257 * |
| Constant | 1,041,898 *** | (2,897,555) * | (3,251,124) * | (3,481,985) * |
| # Observations | 532 | 405 | 367 | 342 |
| Adjusted R ² | 0.66 | 0.78 | 0.78 | 0.80 |

Notes:

[1] GDP (\$MM) is in millions of constant 2014 international dollars representing purchasing power parity. This variable is calculated using "GDP (constant local currency ("LCU")), "GDP (current LCU)," and "PPP conversion factor, GDP (LCU per international \$)," with 2014 as the base year.

[2] All specifications are fixed effect models, to account for both country and year effects.

[3] *** represents statistical significance at the 1% level. ** represents statistical significance at the 5% level. * represents statistical significance at the 10% level.

[4] Number of observations vary between models due to specification differences and data availability.

Sources:

The World Bank, World Development Indicators, October 14, 2015, available at: <http://data.worldbank.org/data-catalog/world-development-indicators>; The World Bank Group, Worldwide Governance Indicators, October 2015, available at: <http://info.worldbank.org/governance/wgi/index.aspx#home>; Strategy Analytics, "Global Smartphone Sales Forecast For 88 Countries: 2007 to 2020," March 2014; Strategy Analytics, "Q3 2015: Tablet Operating System Forecast - Shipments, Installed Base & by Price Tier 2010 - 2019," August 2015.

To test the robustness of our model, we first regressed GDP on only smartphone and tablet units, and year and country fixed effects, as shown in Table 4 column (1). While the fixed effects should account for a great deal of the unobserved variation in GDP, in columns (2) to

(4) we included additional control variables found in the economic growth literature.⁷⁴ Smartphone and tablet units remain positive and statistically significant in each specification. Focusing on our fully specified model of GDP shown in Table 4 column (4), which provides the most conservative estimated effect of smartphones and tablets, we find that each smartphone/tablet shipped is associated with \$11,262 in additional GDP.⁷⁵ This result is consistent across the specifications presented in Table 4.⁷⁶

Another way to interpret the coefficient on the smartphone/tablet variable in our GDP regression is to compare it to the average cost to a consumer of acquiring and using a smartphone or tablet over its life. This comparison results in a multiplier that captures the additional economic activity stemming from smartphones and tablets, over and above (and not including) the money spent by consumers to purchase and own the devices over their useful lives. Assuming, based on 2014 data across a set of countries, an average smartphone/tablet acquisition cost of \$459, an average monthly wireless phone and/or data plan of \$70, and an average replacement time of 31 months, the total cost is over \$2,600 per device.⁷⁷ Thus, the impact of an additional smartphone or tablet on GDP represents a multiplier of approximately 4.3 times the cost to the consumer of owning the device.⁷⁸ These calculations are detailed below in Table 5.

⁷⁴ Specifically, we added control variables based on Barro(1991), followed by the addition of $X_{PATENT_{t,c}}$ based on Ulku(2004), and then the addition of $X_{BBAND_{t,c}}$ based on Czernich et al. (2011).

⁷⁵ Because $Y_{GDP_{t,c}}$ is measured in constant 2014 international dollars using purchasing power parity rates, this coefficient estimate is as well.

⁷⁶ Although not provided in this report, we conducted a number of sensitivities. First, given concerns about potential omitted variable bias, we included data on feature phone sales (i.e., traditional cell phones). In controlling for sales of feature phones, the coefficient on smartphones/tablets in our regression increased. As such, the estimates we report in Table 4 are conservative in that they ultimately suggest a lower economic impact than if we controlled for feature phones sales. We also attempted to control for sales of PCs and gaming consoles, but were unable to find sufficiently comprehensive data, and thus did not control for PC or gaming console sales in our model. Second, we investigated the sensitivity of our standard errors to potential autocorrelation by first clustering our standard errors by year. This had no effect on the significance of the smartphone/tablet coefficient presented in Table 4. We next used Driscoll-Kraay's (1998) covariance matrix estimator that produces heteroskedasticity- and autocorrelation-consistent standard errors. In using the Driscoll-Kraay (1998) covariance matrix, we allowed for AR(1), AR(2), and AR(3) processes. As with our clustering by year, this had no effect on the significance of the smartphone/tablet coefficient presented in Table 4. And finally, we first-differenced our dependent and independent variables to account for potential autocorrelation, and ran our regression on these first-differenced variables. This also had no effect on the significance of the smartphone/tablet coefficient.

⁷⁷ Table 5. Average device purchase price and monthly plan costs are reported in 2014 international dollars using purchasing power parity rates.

⁷⁸ $4.3 = \$11,262 / \$2,647$.

Table 5
Comparable Approach
Cost of Ownership for a Smartphone/Tablet
2014

| Variable | Value |
|---|------------|
| [1] Average Cost of Smartphone/Tablet Cellular Plan | \$70 |
| [2] Average Smartphone Replacement Time (Months) | 31.4 |
| [3] Total Cost of Cellular Plan | \$2,189 |
| [4] Average Cost of Smartphone/Tablet | \$459 |
| [5] Total Cost of Owning a Smartphone/Tablet | \$2,647 |
| [6] Estimated per Unit Impact of Smartphone/Tablet on GDP | \$11,262 |
| [7] Estimated Smartphone/Tablet Multiplier | 4.3 |

Notes:

[1] Calculated as the weighted average price for various types of smartphone and tablet cellular plans. An average plan was determined by averaging all plan prices together for each country with available data, inflating 2013 dollars to 2014 dollars using the World Bank's CPI Index, and then weighting each country's average by shipments in 2014. There were 39 and 38 countries used to calculate the weighted average smartphone and tablet price, respectively. It is assumed that all tablets use a cellular plan. All final numbers are reported in 2014 international PPP dollars.

[2] Replacement time represents the global monthly replacement time from 2014 for smartphones.

[3] = [1] * [2].

[4] Calculated as the 2014 weighted average selling price for both smartphones and tablets by shipment volumes. There were 29 and 6 countries/regions used to calculate a weighted average smartphone and tablet cost, respectively. Numbers are then converted into international PPP dollars first by multiplying by the exchange rate and then dividing by the PPP conversion factor. Final numbers are reported in 2014 international PPP dollars.

[5] = [3] + [4].

[6] From Table 4.

[7] = [6] / [5].

Sources:

Strategy Analytics, "Global Smartphone Replacement Cycle by Country," December 2014; Strategy Analytics, "Q3 2015: Tablet Operating System Forecast - Shipments, Installed Base & by Price Tier 2010 - 2019," August 2015; Strategy Analytics, "Global Smartphone Sales Forecast For 88 Countries: 2007 to 2020," March 2014; IDC, IDC Worldwide Quarterly Mobile Phone Tracker, 2015Q3, November 16, 2015, available at: <http://www.idc.com/home.jsp>; IDC Worldwide Quarterly Tablet Tracker, 2015Q3, November 16, 2015, available at: <http://www.idc.com/home.jsp>; FCC Fourth International Broadband Data Report, February 4, 2015, at 32, 90-100; The World Bank, World Development Indicators, October 14, 2015, available at: <http://data.worldbank.org/data-catalog/world-development-indicators>.

Applying this multiplier to projected VR/AR revenues from the conservative approach results in an additional estimated economic impact of VR/AR technology of \$102.0 billion associated with the potential ecosystem of economic activity that could stem from adoption of VR/AR technology in the high adoption scenario.⁷⁹ If, however, VR/AR shipments represent medium adoption, the associated 68.5 million forecasted units could have a \$43.7 billion economic impact, while low adoption representing 18.5 million forecasted units could have a \$11.8 billion economic impact over the same time period.⁸⁰ These calculations are detailed below in Table 6.⁸¹ Figure 1 displays these economic impact estimates for each year and adoption scenario.

Table 6
Comparable Approach
Estimated Economic Impact of VR/AR Technology (\$B)
2016 – 2020

| | Low Adoption | Medium Adoption | High Adoption |
|---|---------------|-----------------|----------------|
| [1] Estimated Smartphone/Tablet Multiplier | 4.3 | 4.3 | 4.3 |
| [2] Estimated VR/AR Sales Revenue (\$B) | \$2.8 | \$10.3 | \$24.0 |
| [3] Estimated Additional Economic Impact (\$B) | \$11.8 | \$43.7 | \$102.0 |

Notes:

[1] From Table 5.

[2] From Table 3.

[3] = [1] * [2].

Sources:

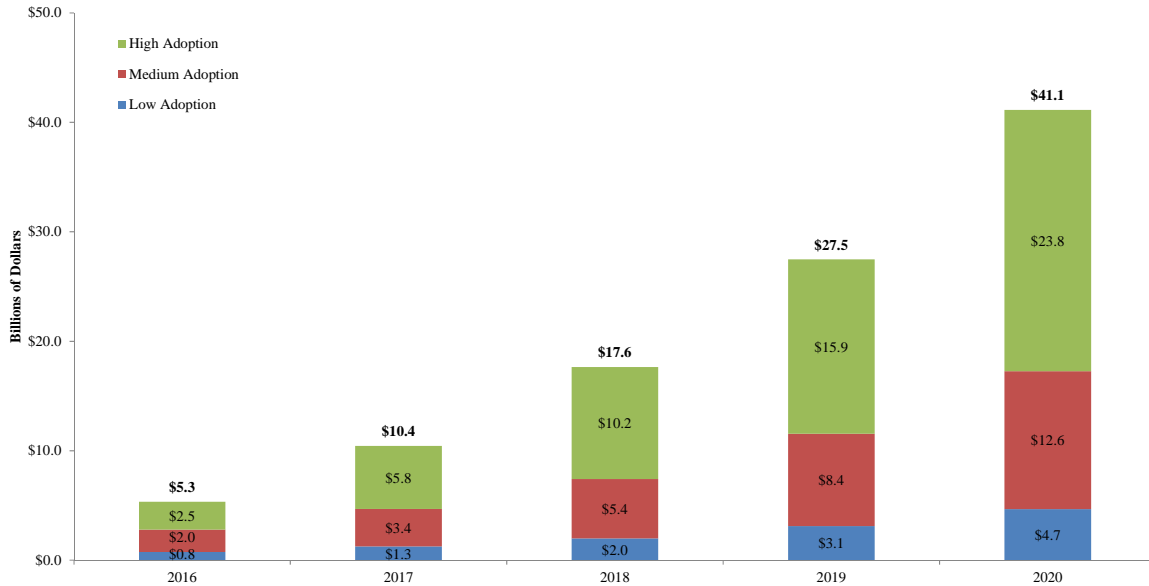
Table 3; Table 5.

⁷⁹ We apply the multiplier to VR/AR headset revenues without accounting for a data plan because we assume most households owning a VR/AR device would already have the relevant broadband and/or wireless data subscription before acquiring the VR/AR device. In applying this multiplier, we also note that we did not account for the cost of computers, gaming consoles and/or smartphones that may be used in conjunction with VR/AR devices since we think it is likely that most households are likely to already have a VR/AR compliant-computer, gaming console and/or smartphone prior to purchasing a VR/AR headset. To the extent our assumption is incorrect, and more consumers purchase a computer, gaming console and/or smartphone for the sole purpose of using a VR/AR headset, our economic impact estimates are understated.

⁸⁰ We also considered another lower and upper bound for these estimates of VR/AR's economic impact associated with the 95% confidence interval around the smartphone and tablet coefficient estimate. While the point estimate is \$11,262 and is significantly different from zero, the 95% confidence interval around that estimate is \$7,140 on the low end and \$15,384 on the high end. This means there is a 95% chance that the true value of the coefficient falls within that range. The additional economic impact of VR/AR based on the low end ranges from \$7.5 billion for low adoption to \$64.7 billion for high adoption. On the high end, that range represents \$16.1 to \$139.4 billion.

⁸¹ If AR headsets are excluded from our comparable approach, we estimate that for VR, the additional economic impact for 2016 to 2020 will total approximately \$7.9 billion for low adoption, \$29.4 billion for medium adoption, and \$68.5 billion for high adoption.

Figure 1
Comparable Approach
Estimated Economic Impact of VR/AR Technology (\$B)
2016 – 2020

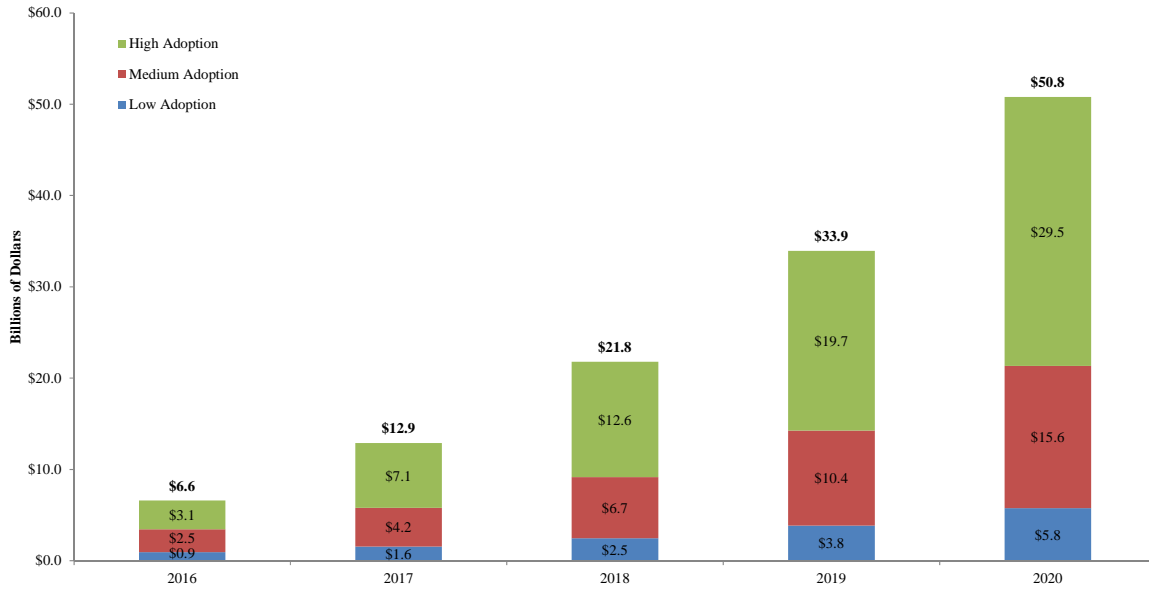


Sources:
 Table 3; Table 6.

Together, the conservative and comparable approaches represent an aggregate estimate of economic impact, including both the revenues generated from selling VR/AR devices in the next five years as well as additional GDP that will potentially be generated by economic activity in the larger VR/AR ecosystem. We estimate the total economic potential of VR/AR technology over the next five years could range from \$14.6 billion in the low adoption scenario, to \$54.0 billion for medium adoption, to \$126.0 billion if high adoption is realized. Figure 2 displays these total economic impact estimates by year and adoption scenario.⁸²

⁸² If AR headsets are excluded from our analysis, we estimate that the total economic potential of VR technology over the next five years could be \$9.8 billion for low adoption, representing the addition of \$1.9 billion in headset revenues and \$7.9 billion in additional multiplier effect capturing related ecosystems of economic activity. This total economic potential could reach \$36.3 billion for medium adoption or could be up to \$84.6 billion for high adoption.

Figure 2
Conservative and Comparable Approaches
Estimated Economic Impact of VR/AR Technology
2016 – 2020



Note:

[1] Numbers reflect the addition of both the Conservative and Comparable Approaches.

Sources:

Table 3; Figure 1.

Overall, we estimate that the economic impacts of VR/AR could range from \$2.7 billion in the most conservative scenario of estimated headset revenues for low forecasted adoption, up to a total economic potential of \$126 billion if high adoption is achieved and the potential for a significant global ecosystem of economic activity related to VR/AR technology is realized. Whether VR/AR remains a niche product or approaches mass adoption with all the potential related developments for complementary products and applications remains to be seen, but in either case (or more likely than not, if VR/AR technology ends up somewhere in between), we expect VR/AR to represent a significant contribution to the global economy over the next five years.