Working Paper Series No. 22

5G Mobile:
Disrupting the Automotive Sector

David J. Teece[1]

1 May 2017

[1] Thomas Tusher Professor of Global Business & Director, Tusher Center on Intellectual Capital, Haas School of Business,, University of California, Berkeley; Chairman; Berkeley Research Group, LLC. Email: dteece@thinkbrg.com.

1 Introduction[2]

1. A recent study by IHS Markit on the economic impact of 5G finds that between 2020 and 2035 5G technology will have an impact on global GDP that is roughly equivalent to adding an economy the size of India to the present global economy. They find that the "value chain" associated with 5G technology will amount to $3.5 trillion (in today's dollars) of output and 22 million jobs. They further find that another $12.3 trillion of output will be "5G-enabled"— i.e., this is the increase in output that 5G enables across a swathe of economic sectors.

2. In this piece, we shed some light on how this enablement effect of 5G likely impacts the economy at the sector level. The "automotive" sector is illustrative. For purposes of this study we liberally address our brief inquiry into the "automotive sector" to including not just the manufacturing of automobiles, but the transportation and logistics sectors too (taxis, trucking, etc.), and the sale of automobiles. We cannot and do not offer a comprehensive analysis of the effects of 5G on all of these different actors within the automotive sector. Instead, we provide examples of how communications functionalities that 5G enables or facilitates will importantly enhance other technological changes that affect the sector.

3. The previously-referenced IHS study focused significantly on the "sales enablement" value of 5G—in effect, capturing the productivity gains from the potential to reform and revamp business practices. 5G also will likely create substantial consumer and social value. The automotive applications of 5G not only highlight the potential for 5G to enable increased productivity and sales, but quite importantly, the social gains from—among other things—improvements in traffic flow, reduced wear and tear on infrastructure and on vehicles, reduced Green House Gas (GHG) emissions and reduced collisions and fatalities. 5G will provide a perhaps substantial boost to so-called "V2X" communications, which in turn will augment and enhance the capabilities of "autonomous vehicles[3]." It is through this mechanism that the social benefits—which in many cases can be easily translated into what economists call gains in output—will be realized. Beyond this, there are obvious "consumer surplus" benefits in that driving or commuting to work is safer, less time-consuming and there may be less for the driver to do, which either frees up time to consume a richer set of media or to use the time to get work done.

4. From a "business model" perspective, the advent of highly communicative vehicles enabled (at least partly) by 5G, could change the competitive interaction between different actors in what one might term the "ecosystem" around automobiles. It could also transform and disrupt the logistics business. For example, with reference to the first type of impact, if consumers came to see a car as the ultimate "connected computer on wheels", what impact will this have on their willingness to pay for the automobile? Will

[2] Research funding supplied by Qualcomm Technologies, Inc. and the Tusher Center. Kalyan Dasgupta provided helpful assistance.

[3] In this paper, "autonomous vehicles" refers to vehicles that have significantly more "autonomous capabilities" relative to the existing stock of vehicles, but not necessarily "level 5" fully autonomous vehicles. For example, autonomous capabilities would include functionality that is sometimes referred to as ADAS (Advanced Driver Assistance Systems).

the traditional automobile manufacturers be successful in their efforts to integrate into the provision of what have traditionally been viewed as services or features "complementary" to the core vehicular experience? Will they become successful "system integrators" or will this mantle instead fall to Silicon Valley firms that effectively outsource the manufacturing of the vehicle to established players in the automobile industry?

5. Of course, since our focus here is on 5G and not on the many other technological developments likely to buffet the automotive sectors in years ahead (e.g., developments in artificial intelligence and robotics), the relevant question for us is the role of the changing communications capability of the car in transforming the business model of the manufacturing sector.

6. Consistent with the ample research (from earlier this century) on the economic impact of Information and Communications Technologies (ICTs), the impact on so-called "using" sectors is critical too. For our purposes, these "using sectors" are the logistics and transportation sectors referred to previously. In this context, we discuss estimates from IHS Markit on the "sales enablement" value of 5G within the logistics and transportation sectors. We also provide some more qualitative insights on the impact of 5G on mobility as a service, a phenomenon that could potentially disrupt not just automobile manufacturers (through its effect on the demand for owning cars) but also transportation providers more broadly (e.g., what if bus service could be obtained "on demand" or buses could have more flexible routes depending on traffic patterns and the location of customer demand).

7. Our overview of the impact of 5G on the "automotive sector" thus encompasses consumers, the manufacturing sector and the using sector. Critical to the motivation for writing this piece is to use the automotive sector to illustrate the "general purpose technology" (GPT) nature of 5G. 5G will put mobile technology at the centre of a global economy characterized by the "Internet of Things." Mobile in the 5G era will transition from being an increasingly significant enabling technology into a true "General Purpose Technology"—that is, a technology that finds economy-wide use, drives complementary innovations in other sectors and becomes a driver of economy-wide innovation and productivity. 5G will make mobile technology a key medium through which devices are connected, information is transmitted, transactions are facilitated and new connected activities are enabled. Given these characteristics, the economic literature on GPTs provides highly relevant insights into the nature and magnitude of the expected impact of a technology such as 5G. The literature clearly suggests that the ultimate economic impact of GPTs is very large. The impact of railroads in England and Wales in 1859 was estimated at 4% of national income but reached 10% of national income in 1890. The impact of Information and Communications Technology (ICTs) in the 1990s was actually even larger than the impact of previous GPTs and arguably occurred with less of a lag. One does not need to postulate that 5G will be as important as railroads in the 19th century or indeed ICTs in the 1990s to appreciate that it will have a very sizable economic impact—even a fraction of the impact of these past GPTs would still be enough to make 5G a significant enabler of growth in the coming two decades. The automotive sector provides a good showcase of the role and effects of 5G, particularly the manner in which it can serve as a platform around which other innovation can occur.

2 5G as an Enabler and Accelerator of Societal Benefits from "Autonomous

Vehicles" and "Smart Cars"

I. 2.1 Autonomous Vehicles, Smart Cars and the Role of Communications

8. As our focus is on 5G, it is critically important to identify the means through which 5G will enable or accelerate the trend towards autonomous vehicles. They have already been enabled to some degree by other technological developments. Artificial intelligence (AI) is typically held to be at the core of the ongoing automotive revolution. While there may be a significant degree of interaction between 5G and these other technological developments, we have tried to be cautious in distinguishing between the benefits of autonomous vehicles as such, and the specific benefits of 5G as an enabler of connectedness and autonomy.

9. Existing research indicates that communications are core to fully recognizing the benefits from autonomous vehicles. 5G will be critical to communications and is likely to contribute to the development of autonomous cars, and may in fact become integral to their functioning. For example, 5G's high bit-rate could enable the upload and download of high volumes of 3D mapping data or the upload of sensor data to develop vehicle autonomy AI. Crucially, the 5G standard is being specifically developed with ultra-reliable and low latency communications (URLLC) and massive Machine Type Communication (MMTC) in mind.[4] Today's 3G and 4G "mobile networks" were developed with consumer voice and data in mind, with machineto-machine communications having only recently acquired prominence. Even where the bandwidth requirements of such communications are not great, the latency and reliability requirements—particularly when these communications become ubiquitous and essential to consumer and business life—will likely be better served by 5G than by any large-scale wireless protocol deployed to date. The low latency and high bit-rate features of 5G may well render it a superior protocol for so-called "V2X" communications. "V2X" spans a gamut of communications abilities: vehicle-to-pedestrian, vehicle-to-vehicle, vehicle-to-network, vehicle-to-mass-transit and vehicle-to-infrastructure etc.

While there is an existing proposed standard to accommodate "intelligent transportation systems"—DSRC (Dedicated Short-Range Communications)—5G will most likely improve capabilities beyond what is possible with DSRC[5] and provide a long-term roadmap for V2X. The momentum in favour of 5G as the standard of choice will be substantial not least because there will be economies of scale and scope in its deployment (i.e., 5G will be the deployment choice for all sorts of other solutions besides intelligent

[4] ITU (2017), "DRAFT: Minimum requirements related to technical performance for IMT-2020 radio interface(s)", https://www.itu.int/md/R15-SG05-C-0040/en.

[5] See Jia, D., Lu, K., Wang, J., Zhang, X., & Shen, X. (2016) "A survey on platoon-based vehicular cyber-physical systems", *IEEE Communications Surveys & Tutorials*, 18(1), 263-284. The study finds that the low packet reception rate and limited transmission range of the DSRC IEEE 802.11p standard can lead to intermittent connectivity and cause difficulty in achieving a sufficiently small handoff latency for cooperative maneuvers. There is some suggestion that even the "Cellular V2X" feature of Release 14 of 4G LTE has superior range and reliability performance relative to DSRC. See 5G Automotive Association (2016) "The Case for Cellular V2X for Safety and Cooperative Driving", http://www.5gaa.org/pdfs/5GAA-whitepaper-23-Nov-2016.pdf.

transportation systems, and of course, it will have greater flexibility than existing protocols to access both licensed and unlicensed spectrum bands).[6]

10. V2X—which 5G is likely to underpin— will itself be a significant driver of benefits from the autonomous vehicle revolution. For instance, consider the issue of highway capacity. One study found that adaptive cruise control ("ACC") by itself resulted only in very modest increases in highway capacity. But using "cooperative" ACC (CACC), which allows for communications between vehicles, there were significant increases in highway capacity at moderate and high penetration levels. Thus at 50% CACC penetration (i.e., 50% of the vehicles in the traffic mix were equipped) highway capacity increased by 22% on average. The increases at universal penetration levels were estimated to be in the order of 50% to 80%.[7] By providing reliable V2X capability, and the cost benefits associated with deploying a technology that also has much broader application than the alternatives (e.g., DSRC), 5G could deliver both the communications capability and the high penetration level required to achieve maximal benefits.

11. Other examples of the benefits from V2X communications in the area of increased highway capacity alone include:

    - So-called "high-density platooning"—the creation of closely-spaced multiple-vehicle "chains" on highways—which would require low latency communications capability. Such platooning improves highway flow while reducing fuel consumption;
    - Coordinated lane changes and coordinated intersections. Both these applications require critical mass penetration of V2X technologies. Both applications have the potential to smooth out traffic flows while also reducing collisions.

12. There are a number of other benefits from 5G and from V2V and V2X communications beyond capacity and flow management. Some benefits include:

    - Reduced collisions, for example, because V2V and V2X communications improve the sensing ability of a vehicle beyond what is apparent from either maps or line-of-sight communications. For instance, high bit-rate and low-latency communications could facilitate the sharing of video information between cars; or sharing of information from pedestrian smartphones and cars;
    - Automatic parking—if cars know where parking spaces are, or can identify alternatives to on-street parking, this speeds up traffic flows and reduces congestion too. Further, it saves time and frustration, and also space: 14% of the incorporated land of Los Angeles County is used for parking, according to some estimates.[6]
    - V2X may be an appreciable enabler of "level 5" automation—for instance, improved sensory abilities of the vehicle will likely be an important factor in determining when and if full autonomy is achieved. When full autonomy is

---

[6] Katsaros, K., & Dianati, M. (2017) "A Conceptual 5G Vehicular Networking Architecture". *5G Mobile Communications* (pp. 595-623), Springer International Publishing. The authors remark "Given that by 2030-2050 nearly all cars are expected to be autonomous, it is emerging that a combination of combination of connected vehicles and autonomy can significantly boost the performance, safety, and reliability of new generations of autonomous transportation systems. *The binding component to achieve this, is 5G communications*." [Footnote omitted, emphasis added].

[7] Shladover, S. Su, D. and Lu, X., (2012) "Impacts of Cooperative Adaptive Cruise Control on Freeway Traffic Flow," *Proceedings of the 91st Annual Meeting of the Transportation Research Board.* Washington, DC. See Figure 1.

achieved, additional value can be created through providing information, entertainment experiences, and productivity tools within autonomous vehicles. The extent to which additional value is provided depends on the quality of connectivity. Here too 5G will be critically important.

13. How large are the societal gains from all of these identified savings or gains? Here, it is admittedly very difficult to distinguish between gains enabled by the totality of autonomous vehicle technology and gains enabled by communications between vehicles (the latter of which we can safely say 5G will be a substantial enabler). Nonetheless some illustrative estimates are provided below:

- Morgan Stanley (2013) finds $1.3 trillion in annual cost savings to the US economy, with $0.5 trillion from accident avoidance, $0.5 trillion from hours on vehicle $0.14 trillion from congestion avoidance, and the rest from fuel savings.7
- Diamandis (2014) estimates that autonomous vehicles could save over 2.7 billion unproductive hours in work commutes, generating an annual saving of $447.1 billion per year in the US (assuming 90% autonomous vehicle penetration).8
- Clements and Kockelman (2017) finds an overall US annual positive impact of $1.2 trillion, or $3,814 per capita. The paper finds that the largest industry impact would be a negative impact on the auto-insurance industry, following a reduction in crashes. This is based on Albright et al. (2015)9, which estimates that the insurance industry will see personal vehicle losses shrink by 60% by 2040. Clements and Kockelman (2017) applies this figure, estimating that the auto-insurance industry would therefore lose 60% of its $180 billion in annual revenue, creating a $108 billion loss. The paper estimates a $1,404 per capita increase in productivity stemming from a gain in work time, finding that the productivity gain, combined with savings from reduced collisions and boosts to the freight transportation, and land development industries

[6] Chester, M., Fraser, A., Matute, J., Flower, C., & Pendyala, R. (2015). Parking infrastructure: A constraint on or opportunity for urban redevelopment? A study of Los Angeles County parking supply and growth. *Journal of the American Planning Association*, *81*(4), 268-286.

[7] Morgan Stanley (2013) "Autonomous Cars: Self-Driving the New Auto Industry Paradigm", https://orfe.princeton.edu/~alaink/SmartDrivingCars/PDFs/Nov2013MORGAN-STANLEY-BLUE-PAPERAUTONOMOUS-CARS%EF%BC%9A-SELF-DRIVING-THE-NEW-AUTO-INDUSTRY-PARADIGM.pdf

[8] Diamandis, P. (2014) "Self-driving Cars Are Coming", *Forbes Magazine*, http://www.forbes.com/sites/peterdiamandis/2014/10/13/self-driving-cars-are-coming

[9] Albright, J. et al . (2015) "Automobile insurance in the era of autonomous vehicles", *KPMG White Paper.*

(among others) will vastly outweigh the negative impacts to the auto insurance and auto repair industries.[8]

[8] Clements, L. and Kockelman, K. (2017) " Economic Effects of Automated Vehicles", *Transportation Research Board Annual Meeting*, http://www.caee.utexas.edu/prof/kockelman/public_html/TRB17EconomicEffectsofAVs.pdf

- Bose and Ioannou (2003) estimate significant savings in fuel consumption (28%) and reductions in air pollution and CO2 emissions (reduced nearly 20%) due to reduced use of rapid acceleration by autonomous cars.[9] The GHG impact of autonomous vehicles—because they improve traffic flow, reduce wear and tear and reduce fuel consumption—is expected to be significant.[10] The benefit of this could be moderated, or potentially outweighed, by an increase in miles travelled by vehicles, caused by an increase in the use cases of autonomous vehicles compared to non-autonomous vehicles.

14. In the next section, we turn to the impact of 5G on businesses. We start with a discussion of the impact of 5G on the "producing" sector as it is commonly conceived—the manufacture of automobiles. The point of the discussion is simply to highlight a range of challenges and possibilities to existing manufacturers and would-be entrants. A critical point is that 5G will be a widely-deployed global standard. As such, it offers a platform around which others (including automobile manufacturers) can innovate. However, the widespread economy-wide applicability of 5G means that in certain areas—e.g., the development of software and content—there may be little sense in developing specific and separate protocols specific to automobiles. Automobile manufacturers can benefit from the possibilities that 5G affords in the area of V2X communications where a tight level of integration with the vehicle per se seems necessary. In other areas, as discussed below, it seems unlikely that automobile manufacturers will be able to earn economic "rents" as platform owners. This is explained in more detail below.

3 5G as a Disruptor of Business as Usual: Impact on the Producing Sector

15. The movement towards autonomous and connected vehicles will, in itself, challenge the automobile manufacturing business as it exists today. Within this movement towards autonomy and connectivity, 5G—which we reasonably hypothesize will be the underpinning of automobile connectivity and a significant enabler of autonomy—offers challenges and opportunities for automobile manufacturers. Two examples illustrate this: (a) although the "market" for in-car entertainment and productivity tools will expand with autonomy and the advent of 5G, the likely beneficiaries of this are not the automobile manufacturers themselves but the same content, software and technology firms that will be prominent in the broader economy; but (b) 5G will offer opportunities for automobile

[9] Bose, A. and Ioannou, P. (2003) "Analysis of Traffic Flow with Mixed Manual and Semiautomated Vehicles," *IEEE Transactions on Intelligent Transportation Systems* 4,173-18.

[10] Road vehicles in the US expelled 1.4bn MT of CO2 equivalent in 2015 according to the EPA (Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015, ES-11, https://www.epa.gov/ghgemissions/inventory-usgreenhouse-gas-emissions-and-sinks-1990-2015). We take a carbon social cost of $42 per MT of CO2 equivalent in 2015 US dollars (https://www.epa.gov/climatechange/social-cost-carbon). If the 20% CO2 reduction that Bose and Ioannou (2003) find in rapid acceleration situations holds more widely, this leads to a social cost saving estimate of $11.76 billion annually, ceteris paribus.

manufactures to innovate and capture significant value in the area of vehicle-to-vehicle and vehicle-to-infrastructure communications.

16. Both these effects are linked to the very nature of a standard, such as 5G. A standard offers the key economic benefits of interoperability and compatibility. Standards make products more valuable to consumers since compatible products can be interconnected to each other, enabling the emergence of large networks of users. These large networks also add value to manufacturers of standards-based products, because these manufacturers can benefit from economies of scale in development and production. Innovators and developers also benefit from reduced uncertainty—the standard allows for innovators and developers to invest with confidence that their products will be compatible with other communications products, and that they will have access to a broad marketplace enabled by the standard. The standard thus shapes a platform around which innovation coalesces.[11]

17. In the context of "in-car" entertainment and productivity tools, the 5G standard will create a vast marketplace which will foster innovation in other "complementary" areas. However, it will be difficult for automobile manufactures to compete with their own operating systems, content and software against those who can easily leverage their 5G-based products into automotive applications. The firms that are large players in the wider entertainment, "apps", and productivity tools areas in the wider economy will enjoy scale and cost advantages directly enabled by the presence of a standardized technology that is used for connectivity purposes across the entire economy, not just for automotive connectivity (in this case 5G). Users will demand compatibility and seamless continuity between the smartphone or device environment outside the car and that inside the car.

18. At the same time, the trend towards autonomous vehicles offers other possibilities still, which 5G can also influence. Here, automobile manufacturers may be in a good position to integrate their existing manufacturing capabilities with new developments in artificial intelligence (at least when it comes to developments geared towards automotive applications). It seems sensible to posit that the development of V2X communications will require a much more automobile-specific adaptation of communications technologies and protocols than would, say, entertainment or work-productivity software. Here, 5G technology will provide the benefits of inter-operability, compatibility with other communications producers, and scale or network effects that standardization provides. By doing so it will lower the barriers to participation in, and improve the commercial case for, significant innovation in the development of vehicle-to-vehicle and vehicle-to-infrastructure communications capabilities. In the development of such capabilities, existing manufacturers may be well-placed to claim a share of the higher value-added inherent in autonomous communicative vehicles.

19. A more basic question is whether autonomous and connected vehicles, and the 5G communications capability within them, will have an impact on the demand for passenger cars, or at least on conventional modes of ownership of passenger cars. Mobility-as-a-service (MaaS) offers a vignette into the issues that could arise. Even with current technology, MaaS trials (e.g., in Helsinki, Finland) offer travellers the change to specify their travel needs and then integrate across platforms to achieve the lowest-cost, highest-convenience travel path. For instance, one might make the first leg of one's journey by subway, and then seamlessly transfer to a ride-sharing service for the second leg, being able to pay for both services upfront. If one got off the subway or bus one stop early, for example, then this could be communicated to the ride-sharing service, or indeed the second leg of the journey could instead be adapted readily to feature some other mode

[11] An overview of the economic benefits from standardization can be found in Grindley, Peter, "Standards, Strategy and Policy: Cases and Stories", Oxford: Oxford University Press (1995), pp.20-29.

(e.g., bus). Similarly, if traffic conditions change, then instead of getting off at subway stop A to catch their ride for the next leg of the journey, the traveller could "on the fly" re-engineer their travel plans. Clearly, low-latency and ultrareliable cellular communications, i.e., 5G will only accelerate the emergence and attractiveness of such services.

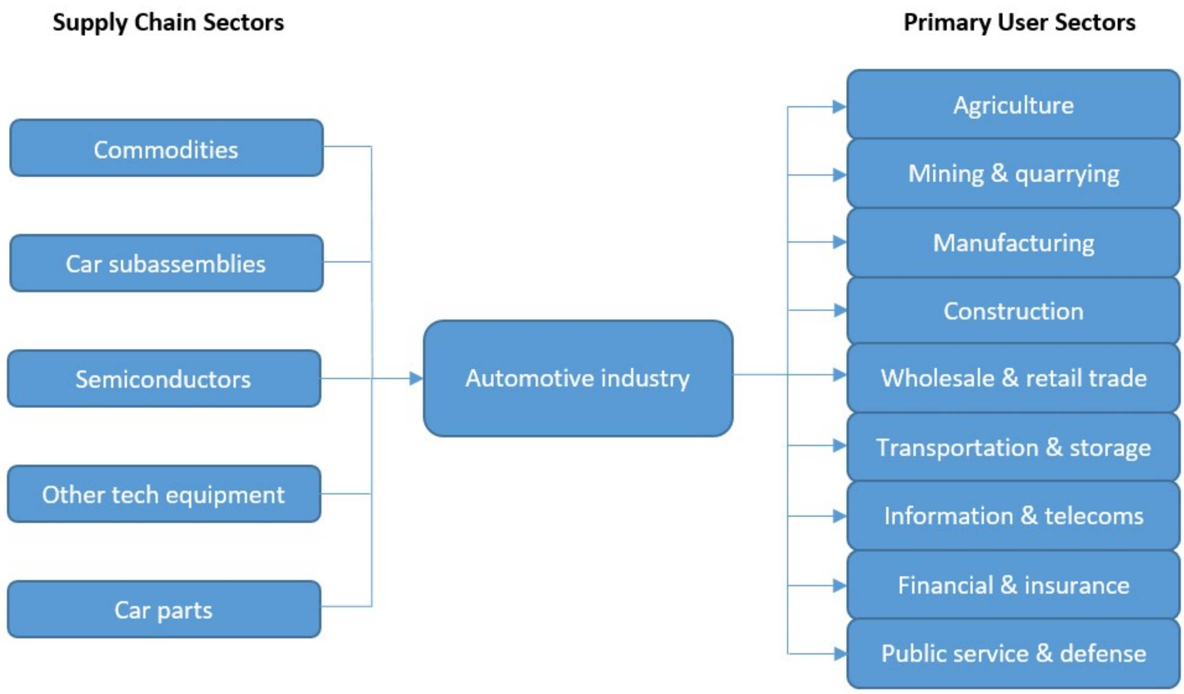
20. One possible impact of such services is 5G platforms will that it will reduce the dependence of travellers on predictable and pre-planned modes of travel. Further, by enhancing the attractiveness of "on demand" or shared ownership services, the demand for ownership of passenger cars might decline. Alternatively, the rationale for car ownership may change from an essential or at least important means to get around to an increasingly discretionary and leisure-oriented option. The extent of the impact on car ownership will depend on whether the MaaS phenomenon is focused on areas where there are already good alternatives to car ownership (European cities, New York, Tokyo) as against areas where currently alternatives to car ownership are underdeveloped or not cost-effective (Asia, the suburban U.S.). It is interesting to note, however, that even in the car-oriented United States, the proportion of 18year olds with driving licenses is much lower than it was 20 years ago, indicating that younger people are anyway less wedded to the car. This may also suggest that they will be receptive customers for MaaS or similar offerings.

21. The impact of new modes of ownership or travel will also affect the "using" sectors—mass transit, taxi services, and logistics. These impacts are discussed next.

4 5G as a Disruptor of Business as Usual: The Using Sectors

22. A larger and more productive automotive sector means enhanced sales and productivity for both the sectors that supply the automotive sector and for sectors for which the automotive sector is a supplier. In these latter sectors, there is significant use of automotive equipment in day-to-day business. Figure 1 offers a schematic diagram of the primary supplying and "using" sectors linked to the automotive industry.

II. Figure 1: Supplying and Using Sectors Linked to the Automotive Sector



23. IHS Markit's January 2017 study of the economic impact of 5G points out that beyond the savings to society discussed above, 5G-enabled autonomous vehicles will have significant benefits in industrial and commercial applications. An obvious benefit is reduced operating expenditure (op-ex) as a result of needing fewer drivers and using more efficient routes. Reduced wear and tear and reduced fuel consumption provide further savings. From a revenue-enhancement perspective, more efficient routing and longer hours of operation should likely prove beneficial to sectors such as wholesale and retail trade, transportation, logistics and warehousing. Ultra-low latency and ultra-reliable communications will also permit the operation of automotive equipment (unsupervised) for longer periods of time and at lower cost than is currently possible. This will benefit sectors such as agriculture, construction and mining and quarrying, perhaps having a transformative impact.[12]

24. In their January 2017 study, IHS Markit calculate what they call "5G-enabled" global sales activity. This is the incremental sales activity across multiple industrial sectors that will be enabled by 5G—i.e., taking into account the sales activity that would already occur with pre5G technology. After a ramp-up period in the late 2020s and early 2030s, they estimate the total global sales enablement potential of 5G to reach $12.3 trillion in 2035, or 4.6% of

[12] IHS Economics/IHS Technology, "The 5G Economy: How 5G Technology Will Contribute to the Global Economy", January 2017, Appendix A. In the interests of precision, the sectors listed as "primary user sectors" are defined in terms of the ones that are most powerfully impacted by changes in the automotive sector resulting from implementation of 5G technology.

real global output that year. Of this, some $3.4 trillion of the impact will be felt in the manufacturing sector.

25. IHS have more recently prepared estimates of the sales enablement effect in the automotive sector and its "using" sectors. IHS calculate that the total sales enablement effect of 5G in the "vertical" segment (the automotive sector and its suppliers) will reach $467 billion in 2035. In the "using" sectors, they calculate that the sales enablement benefit will reach $1.437 trillion in 2035. The total sales enablement is $2.410 trillion when one includes the impact on the upstream sectors that supply the automotive segment. In short, some 19.6% of the total calculated sales enablement of $12.3 trillion in 2035 is linked to the automotive sector. This high proportion is indicative of the impact that 5G technology will have on the automotive sector, highlighting the appropriateness of using this sector to showcase the economic impact of 5G.

III. Table 1: Sales Enablement in 2035

Sales Enablement due to 5G in the Automotive Industry, 2035 ($ billions)	
A. Sales Enablement in "Use" Sectors	**$1,437**
Sectors include agriculture, mining and quarrying, manufacturing, construction, wholesale and retail trade, transportation and storage, information and telecoms, financial and insurance, public service and defence.	
B. "Within"-Automotive Sales Enablement	**$467**
% of automotive industry sales Examples include auto manufacturing, sales and services.	3.8%
C. Supply Chain Enablement	**$506**
Tier 1 suppliers Extended supply chain	150 355
D. Total Sales Enablement from Automotive 5G	**$2,410**
% of $12.3 trillion 5G Sales Enablement	19.6%

Source: IHS Economics/IHS Technology.

5 Conclusions and Policy Implications

26. The previous sections have discussed the very substantial social and sales-enabling benefits stemming from the application of 5G technology in the automotive industry. These benefits may amount to trillions of dollars annually for the U.S. economy (as an example) from increased productivity (e.g., saved commute times, and ability to work and process information while commuting in the car); increased environmental quality, which has a dollar value in its own right; and reductions in traffic collisions and fatality rates. Beyond this, we have discussed the sales enablement effects—the 5G-enabled increase in

sales of the automotive sector, key using sectors, and the upstream sectors that form the "supply chain" of the automotive sector. Beyond this, of course, there will be significant changes—likely with huge consumer conveniences and social savings, but with unpredictable impacts on which some firms "win" and other firms "lose." The advent of "Mobility-as-a-service", for instance, promises to change patterns of car ownership and commuting, but with potential impacts on existing conventional models of ownership and provision of transportation. The car as an ever-richer "connected" environment also offers challenges and opportunities for firms; but is likely to be highly beneficial for consumers and society.

27. Are there constructive policies that can ensure and even accelerate the realisation of these benefits? It is obvious that public policy must not stand in the way of the fundamental research and development activity currently underway to facilitate the ultra-reliable and ultra-lowlatency systems that 5G enables. Economic literature demonstrates that social returns from key innovations dominate private returns—that is, what society gets by way of additional value from these innovations far exceeds the value that the innovator is able to realize.[13] This fundamental facet of innovation means that great care must be taken to ensure that policy interventions in the area of intellectual property are appropriately aware of the risk that socially valuable innovation is foregone because policy interventions create wariness among innovators about their ability to recognize appropriate value for their contributions to standards. Inasmuch as much of the technology must be licensed for it to impact standards and have impact, licensors must be fairly rewarded or the R&D spigot will quietly close and downstream implementers suffer too.

28. At a more focused level, some proposed policy measures that could facilitate the benefits discussed above are: (a) requiring or incentivizing the co-installation of fiber and power as a routine part of road repair works—this would facilitate the emergence of intelligent transportation systems that utilize cellular mobile connectivity; (b) requiring V2X equipment in cars for certification purposes; (c) lanes and parking spaces for autonomous vehicles, e.g., lanes for cars equipped with vehicle-to-infrastructure and vehicle-to-vehicle communications that are able to "platoon", (d) improved location accuracy requirements for calls and data transmission from wireless devices, and (e) faster speed limits for autonomous cars.

29. Finally, spectrum regulatory policies also have an enabling role to play. The 5.9 GHz spectrum band is being considered globally for Intelligent Transportation Systems (ITS) and safety applications – and also for the above mentioned V2X communications. In Europe, for example, the 3.5 GHz spectrum is useful for augmenting V2X operation in 5.9 GHz to support network-based 5G automotive use cases with high bit-rate usage, thus supporting many broader industrial and consumer-oriented applications. Given the "mission critical" nature of some automotive applications, timely release of a sufficient amount of dedicated spectrum for ITS would appear to take on importance in this case especially in view of the future of connected and automated driving. The re-use of ITS infrastructure by mobile operators deploying 5G, perhaps even through collaborative efforts that overcome any

[13] This economic literature goes back many decades. Two pioneering studies in this regard are: Griliches, Z. (1957), "Hybrid Corn: An Exploration in the Economics of Technological Change", *Econometrica*, Volume 25, Number 4, pp.501-522; and Mansfield, E., J.Rapaport, A. Romeo, S. Wagner and G. Beardsley (1977), "Social and Private Rates of Return from Industrial Innovations, *Quarterly Journal of Economic*s, Volume 91, Issue 2, pp.221-40.

hurdles related to the business case for such deployments, would be other important policy measures that would foster the benefits we discuss above.[14]

[14] A summary of some of the spectrum related (and other) policy considerations can be found in the Analysys Mason white paper for Qualcomm, entitled "Regulatory Options to Promote Investment in 5G and IoT in Europe", 2016.