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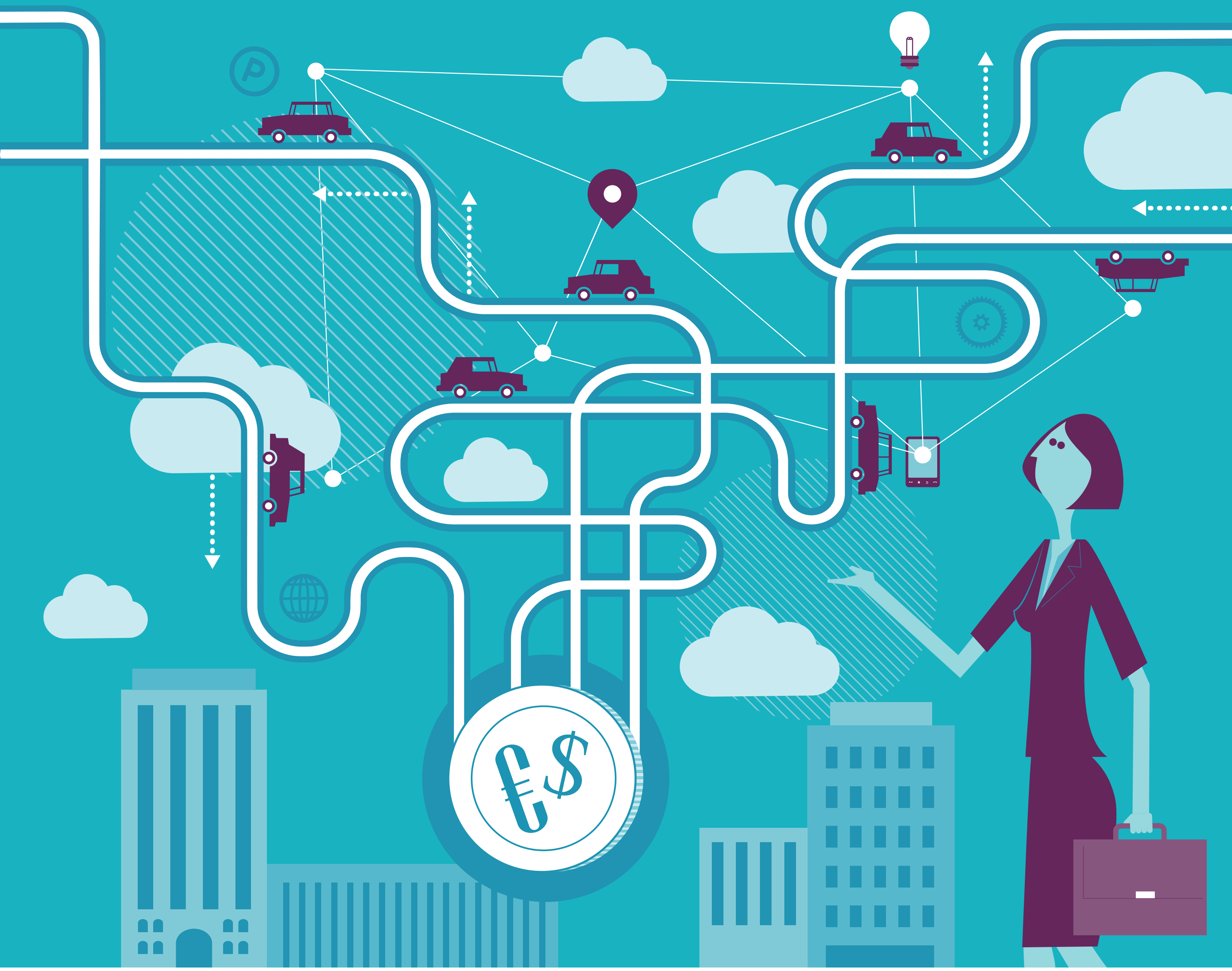

The Value of Connectivity in the Automotive Sector

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The Value of Connectivity in the Automotive Sector

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1. Introduction

The automotive industry is rapidly adopting connectivity technologies for diverse reasons, including safety, infotainment, and preventive maintenance to name a few of the emerging smart car applications, which are often collectively termed, the connected car or vehicle.[2] Connectivity technologies are not only providing the means for these smart vehicle services, but they are also facilitating the transformation of the industry from an automotive to a mobility focus that is disrupting traditional value propositions and creating new business models and sources of value. For example, McKinsey Advanced Industries (2016) predicted that on-demand mobility and data-driven services could account for approximately $2 trillion (or approximately 30%) of the automotive revenue pool by 2030, with data connectivity services accounting for between $450-$750 billion per year. This growth is built upon advanced mobile telecommunication standards, in particular, cellular standards, which provides the enabling infrastructure for new connectivity-based products and services to emerge in the automotive/mobility sector. These standards are developed in an open, consensus-based process by a consortium of market actors through what are known as standard development organizations (SDOs).[3]

In general, it is not controversial to state that the emergence of the connected vehicle is a great source of value for producers, consumers, and society as a whole. A review of the annual reports of leading automakers confirms that connectivity is considered one of the four critical megatrends facing the automotive industry together with autonomous driving, shared mobility, and electrification, where connectivity can be seen as both a separate and integrated value proposition to these other megatrends.[4] Below are just two examples of many where automotive leaders have defined the importance of connectivity.

> But the transformation of the car will go far beyond drives. It is becoming a highly complex, connected device, like a "tablet on wheels", if you like.
> - Herbert Diess, Chairman of the Board, VW Group in Letter to Shareholders, 2018

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[2] The term, connected vehicle, will be used throughout this study as an umbrella term for the total market for connectivity-enabled automotive products and services. For the most part, it will refer to automobiles and light trucks, excluding heavy trucks, except where explicitly mentioned.

[3] 3GPP, MPEG, and IEEE are examples of SDOs that have developed some of the world's most widespread technology standards.

[4] See, for example, Toyota Annual Report (2018), VW Group Annual Report (2018), BMW Annual Report (2018), and Daimler Annual Report (2018) among others.

> Our aim remains to be both a driving force and an innovator, able to lead individual mobility into a new era for our customers: one that is sustainable, connected and autonomous.
> - Harald Krüger, Chairman of the Board, BMW in Letter to Shareholders, 2018

Additionally, Dr. Dirk Hoheisel, member of the board of management of Robert Bosch GmbH, summarized the results of the Bosch study Connected Car Effects 2025, stating "our study shows that the effects of connectivity will have a perceptible impact on every driver in 2025."[5] Furthermore, McKinsey (2018) found that 40% of respondents to their global survey would be willing to change car brands for better connectivity services, which is a result that has remained constant for the previous four years.[6] Thus, the current evidence is that automotive connectivity is a differentiating factor in the short run and a strategic factor facilitating the transformation of the automotive industry in the future.

Thus, the questions of how new connectivity-based revenue sources will be generated and monetized and by whom are currently one of the most critical strategic issues facing the automotive industry.[7] The answers to these questions are particularly challenging given the convergence of information and communication technology actors into the traditional automotive value chain, which leads to a clash of norms over intellectual property, business models, and the distribution of value.[8] Thus, the overarching goal of this paper is to create greater clarity over the value that connectivity brings to the automotive industry to highlight opportunities and reduce transaction costs for those convergent actors working to construct new markets and services for connected vehicles.

To the author's knowledge, this is the first study of its kind that attempts to define the economic context of connected vehicles and start to measure the current and future value generated by emerging applications. Therefore, this study will both aggregate and contextualize existing public data and predictions, and where possible, provide calculations to

[5] Bosch (2017)

[6] The results were different across countries, for example, China (69%), Germany (19%), and US (34%).

[7] McKinsey (2014) states "the connected car trends are among the most shaping industry forces – with new players entering the competitive stage while incumbent OEMs and suppliers are trying to define, defend, and expand their competitive positions. Eventually, both regulation and consumer preferences will decide how these trends may play out and how they will impact the profit pools and the success factors for the participating players, automotive and nonautomotive players alike."

[8] See Roland Berger (2013) for a discussion on the strengths and weaknesses of different old and new actors in the automotive value chain with regards to their ability to capture new sources of value.

both exemplify valuation models and provide preliminary value estimates.[9] While vehicles employ numerous connectivity technologies, including Bluetooth, satellite, and WiFi, among others, much of the growth in connected vehicle functionality is predicated on current and future advances in standardized cellular technology.[10] As connected vehicle solutions operate through cellular connectivity from both smartphones and embedded vehicle devices, an effort is made to inform the reader when these two devices are aggregated and differentiated in the value analysis. Finally, it should be understood that the value of connectivity in automotive applications is dynamic from the perspective of the technology itself, the pace of development of innovative solutions, and the transformational nature of the automotive/mobility market.

The paper is broken down into the following sections: (1) a brief overview of the emergence of the connected vehicle, (2) a theoretical overview of the measurement of economic value, (3) connected vehicle use cases, value propositions, and valuation models, (4) the quantification of the value of automotive connectivity, and (5) a concluding discussion.

2. The Emergence of the Connected Vehicle

Connectivity is becoming so ubiquitous that it is easy to overlook. In automobiles, we have become accustomed to remote keyless entry, GPS, Bluetooth-integrated mobile phones, and most recently, embedded communication units that turn the vehicle into a smartphone on wheels.[11] In the area of mobility and ride-sharing, there would be no Uber, Lyft, etc. without connectivity. In the future, the role of connectivity will likely grow in importance with the increased use of vehicle-to-everything (V2X) technology and the development of autonomous vehicles. The changing role of connectivity in the automotive context will have a direct impact on its value contribution over time, as will be discussed later. This section will provide an overview of the emerging concept of the connected vehicle, illustrating emerging functionality, complementary and competing connectivity standards, and different modes of

[9] In addition to consultancy reports and other public sources, Statista was used as a key source of connected vehicle data through the Stanford University license.

[10] Connectivity technologies that compete in specific applications with cellular technology are also applicable. Aggregate data of connected vehicle revenues can contain more than one applicable connectivity technology, but the focus is primarily on cellular-based connected vehicle segment and related applications. An effort has been made to inform the reader when applicable.

[11] See Economist (2014) describing how mobile communication is changing the way cars are made, bought, and driven.

connectivity leading to the competition for control of the automotive ecosystem for delivery of connectivity-enabled services.

2.1 The Concept of the Connected Vehicle

The concept of a connected vehicle is evolving, but definitions are starting to emerge. For example, McKinsey (2014) states that the "connected car or car connectivity comprises the set of functions and capabilities that digitally links automobiles to drivers, services, and other automobiles. The various features serve to optimize vehicle operation and maintenance as well as driver comfort and convenience." IDC defines a connected vehicle more technically as "a light-duty vehicle or truck that contains a dedicated cellular network wireless for wide area connection that interfaces with the vehicle data (e.g., gateways, software, or sensors)."[12] Figure 2.1 below provides a schematic of the emerging connected vehicle described as vehicle-to-everything communication (V2X) that can seamlessly connect with pedestrians (V2P), road/city infrastructure (V2I), other vehicles (V2V), and to the broader network (V2N).

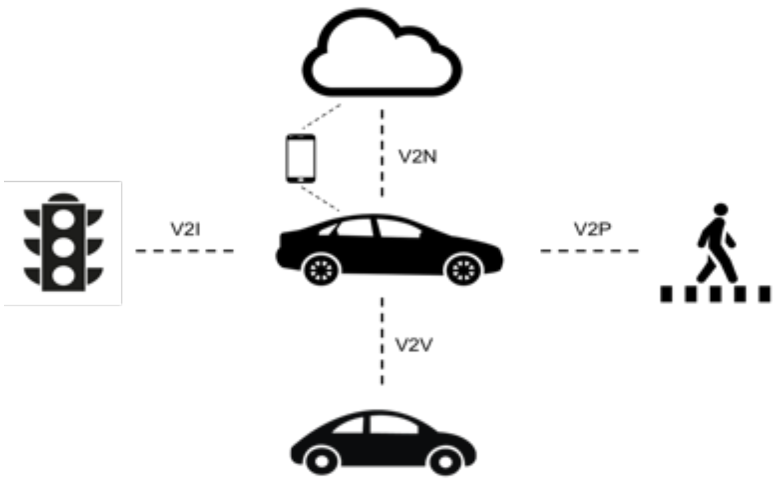

Figure 2.1. Overview of future vehicle-to-everything (V2X) environmental interfaces.

As of now, the focus has been on connectivity in general, but there are, of course, many different technical connectivity solutions or standards. Connectivity standards are often grouped into categories that define their key characteristics, such as distance, bandwidth, power, etc. For example, Bluetooth and Zigbee operate in the short-range, WiFi operates at

[12] See https://www.idc.com/getdoc.jsp?containerId=prUS45092819.

mid-range, and cellular at long-range, in addition to satellite communication.[13] Newer standards with lower power consumption and lower latency are also emerging. Below is an illustration of the connected vehicle with different connectivity standards depicted that serve different uses cases.

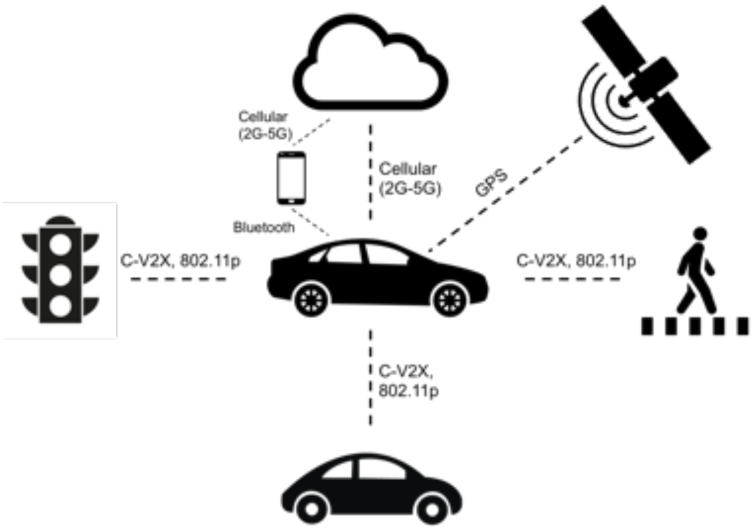

Figure 2.2. Mapping of vehicle connectivity and communication standards.

As one can see from figure 2.2, connectivity standards are both complementary (e.g. Bluetooth for short-range and cellular for medium-long range) and competitive (IEEE 802.11p and 3GPP C-V2X). The fact that connectivity standards have overlapping functionality and compete directly in different applications is helpful to understand their relative value as market actors make implementation choices based on technical performance and customer needs. For example, V2X is sizing up to be a standards war between DSRC (WiFi) and C-V2X (cellular) with large automotive actors in both camps.[14]

[13] Newer cellular standards, such as 4G/5G, can also operate effectively in the mid-range in competition with WiFi.

[14] The choice of V2X connectivity standards is also highly contested on the political arena in Europe, whereby the European Council in July 2019 reversed an EC directive that had been approved by the EU parliament on April 17th that would have mandated DSRC WiFi 802.11p over the competing cellular (LTE/5G) alternatives. Now market actors in the EU will likely have the ability to choose.

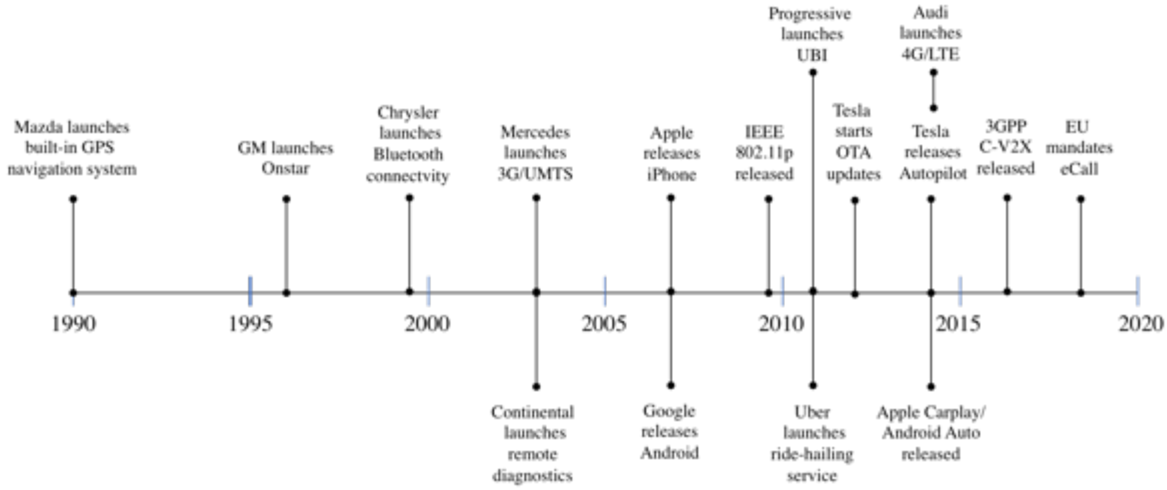

Figure 2.3. Timeline of selected connected vehicle milestones.

Above, figure 2.3 presents a timeline of the development of the connected vehicle, highlighting several key milestones over the past thirty years. Early versions of remote keyless entry can be traced back to the early 1980s, but it could be argued that the connected vehicle era began in earnest in 1996 with the introduction of the Onstar system by General Motors. Embedded 3G/4G functionality and seamless integration of smartphones followed in the 2000s, which facilitated the development of numerous applications, such as advanced navigation using both GPS and cellular connectivity, in-vehicle hotspots for infotainment, and more recently, over-the-air (OTA) updates, among numerous others. With the advent of V2X and autonomous vehicle functionality, connectivity is positioned to be a core, ubiquitous technology that is fundamental to vehicle operations and delivery of services that define the consumer mobility experience.

2.2 The Battle for the Connected Vehicle Ecosystem

As discussed in section 1, the debate as to whether all vehicles will be connected is over. The remaining questions are how will they be connected, for what purpose, and who will capture the value that flows through the automotive ecosystem. Historically, there have been three basic modes of connectivity solutions through which automotive services flow:[15]

[15] See GSMA (2012) for a more detailed discussion, statistics, and forecasts.

- Embedded solutions - a solution where the connectivity functionality is built into the car.
- Tethered solution - a solution where a separate mobile device (e.g. smartphone or 3rd party device) is used as a modem (e.g. through a wire, Bluetooth, or WiFi) to enable connectivity.
- Integrated/Mirrored solution - a solution whereby smartphone applications are integrated or mirrored into the vehicle infotainment system allowing for a safer and more natural interaction with the driver (e.g. Apple Carplay and Android Auto).

As automakers have realized that controlling the connection with the customer is critical to generating revenue from automotive connectivity, nearly all automakers have pledged to install embedded solutions in all of their new vehicles in the near future.[16] IDC (2019) estimates that by 2023 nearly 90% of new vehicles in the United States and 70% of worldwide vehicles will be shipped with embedded connectivity.[17] In Europe, embedded solutions have been facilitated by an EU mandate that Emergency Call (eCall) technology must be available in all new vehicles sold from April 2018.[18] Thus the vehicle is emerging as the next major digital platform, setting-up an intense competition between the emerging vehicle ecosystem based on embedded connectivity and the incumbent mobile ecosystem based on smartphone connectivity and application platforms (e.g. iOS and Android) with their associated 3rd-party developer networks. For example, advanced navigation applications can be delivered through a vehicle service subscription (e.g. GM Onstar) or a smartphone app (e.g. Waze) through the Apple/Android platforms. While certain applications favor smartphones, such as ride-sharing services, other emerging services such as safety, security, over-the-air updates, and tolling, among others, favors embedded solutions.[19]

[16] For example, Ford has pledged to connect all its vehicles by 2019 (https://media.ford.com/content/fordmedia/fna/us/en/news/2018/03/15/ford-readies-north-americas-freshest-lineup-by-2020.html) and Toyota by 2020 for all its Japanese and US vehicles (Toyota Annual Report 2018)

[17] IDC (2019), Worldwide Connected Vehicle Forecast, 2019-2023.

[18] https://ec.europa.eu/digital-single-market/en/news/ecall-all-new-cars-april-2018.

[19] See GSMA (2012) for an analysis of applications for different connectivity solutions. PAYD insurance services are an interesting exception at present whereby 3rd party tethered devices are still currently dominant.

3. Measurement of Economic Value

In this section, fundamental concepts of economic value are explored including (1) the distribution of value among producers, consumers, and society, (2) value logics and models for the valuation of technology, and (3) an overview of valuation methods for technology-based products and services.

3.1 Concepts of Economic Value Distribution

Value is a subjective concept as its meaning and magnitude are dependent on both the context of the valuation and the market. It immediately brings forward two essential questions - value of what and for whom. When we think in terms of an economic system related to a good or service (i.e. the what), it is useful to think about value creation across three different social actors (i.e. the whom) - producers, consumers, and society as a whole.

Figure 3.1 below provides a simple, static economic model to illustrate the different economic actors and concepts of value distribution.

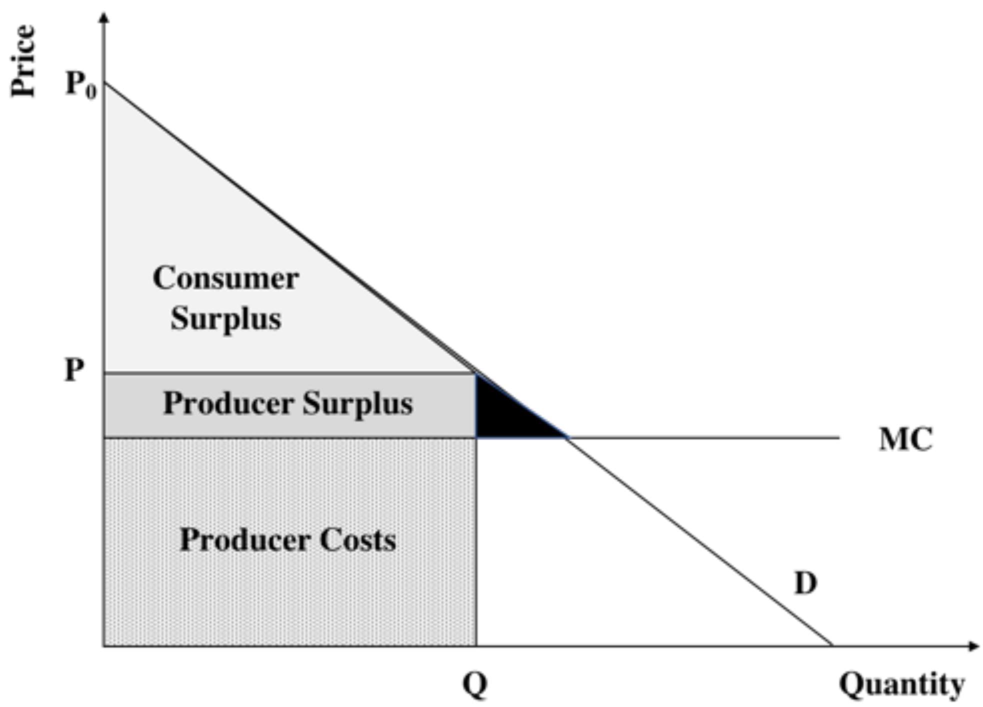

Figure 3.1. Economic model of value distribution in a market.

Below are described three measurement concepts of value based on the different economic actors and the model in figure 3.1 above:

1. **Total Market Revenue/Value** - this is based on the price of a good/service on the market (i.e. supply and demand), whereby the total market value of a good/service is equal to total revenue (TR). This is represented in figure 3.1 as P*Q or the sum of producer surplus and costs.

2. **Total Economic Value** - this is based on the subjective benefit derived from a good/service by the consumer, which is often described as the consumer's willingness-to-pay (WTP). This is represented in figure 3.1 by $P*Q + ½(P_0-P)*Q$ or the sum of consumer surplus and producer surplus and costs. Thus, this includes the total market value plus the consumer surplus, which is a source of value that is not measured through a market transaction.[20]

3. **Net Social Value** - this is based on the total value impacting society that is both included and excluded from the market pricing mechanism. From a static perspective, in addition to total economic value, this would include any deadweight loss generated by producer surplus as well as externalities, both positive and negative. Externalities from the perspective of an individual market (i.e. partial equilibrium analysis) can be viewed as both non-priced societal impacts or as value transfer (both positive and negative) to other markets (i.e. a general equilibrium analysis).

These three different measurements of value provide a useful framework to understand the creation and distribution of value in a market economy across producers, consumers, and society as a whole. Value in relation to these three social actors is described below:

- **Producers** - this includes all actors in the value chain that contribute to the production of the particular good/service on the market (i.e. the source of supply). Producer value is measured using the Market Value. Its components are producer surplus, which is equal to profits plus fixed costs, and producer's costs, which is equal to variable costs. These economic costs differ from accounting costs as they include opportunity costs as well.

[20] Another way to understand this from a market perspective is to view consumer surplus as potential producer surplus, which could be achieved through perfect price discrimination.

- **Consumers** - this includes the actors that purchase goods/services on the market (i.e. the source of demand). Consumer value is measured using Economic Value. Its components are Market Value and Consumer Surplus, which is the difference between consumer willingness-to-pay (WTP) and the price that they actually pay on the market. Market competition and innovation are two key processes that lower the quality-adjusted prices of products and services over time, leading to increases in consumer surplus.

- **Society** - this includes all actors in society, whether they participate in the specific market or not. Societal value is measured as Net Social Value. Its components are Economic Value plus externalities, both positive and negative, that are not priced in the market. Thus, it is possible that the net social value generated by a market could be less than the economic value if significant negative externalities are present. A good example would be pollution, which inflicts a negative cost on society that is typically not fully captured through market prices.[21]

3.2 Valuing Technology

The value of technology is a challenge to measure as efficient technology markets do not typically exist from which market prices can be easily observed, in contrast to typical market-based products and services, such as automobiles or mobile subscriptions (Lev, 2001). This is especially true for enabling technologies and multi-technology products (Teece, 2018). Thus, when the value of technology cannot be observed through market transactions, it must be determined through an investigation of the contribution it provides to the value for the consumer - what is typically defined as its value-in-use (VIU) (Sullivan, 1998). This section will focus on the fundamental value logics and models that define the VIU of technology that is delivered through products and services to consumers on the market.

Value Logics

Technology-based innovation generally provides value through the following two mechanisms or logics:

[21] For example, proposals for carbon credits and taxes are means to price (i.e. internalize) negative environmental externalities into the market system.

1. **Improvements to existing products and services** - technology improvements can range from incremental to radical and typically provide efficiency and performance benefits to existing value propositions (e.g. anti-lock brakes, more fuel-efficient diesel engines, or advanced navigation systems).

2. **Creation of new products, services, or business models** - technology creation opens the market to entirely new value propositions or business models that either eliminate existing solutions through creative destruction or launch completely new markets for products and services (e.g. ride-sharing apps, over-the-air updates, and autonomous driving).

Value Models

Market value is typically generated through the following two economic models:

1. **Direct value creation** - this includes the value that is directly measurable from market transactions by applying accounting concepts and principles, for example:

    - **Revenue generation** - from an accounting perspective, the top-line total revenue (TR) constitutes the total quantity of products or services sold (q) multiplied by the price (p), which equals (q*p). For a technology that creates or enables new products and services, the total revenue is applicable for the calculation of VIU for the technology. For a technology that improves the performance (i.e. utility) of existing products and services, the incremental value added due to the technology must be calculated, that is, the increase in revenue due to the technology (ΔTR). A change in revenue (ΔTR) can be affected by either an increase in quantity sold (Δq) through growing market demand or increased market share of the existing market or through an increase in price (Δp), which is often referred to as a price premium (Parr, 2018). Subscription-based business models, such as those provided by GM Onstar for vehicle connectivity, exemplify the revenue generation value model.

    - **Cost reduction** - from an accounting perspective, total cost (TC) constitutes the total quantity of products or services (q) sold multiplied by its cost of sale (c), which equals (q*c). The value of technology improvements that generate cost reductions through increased efficiency can be calculated through the decrease in total costs (ΔTC) due to the technology. In highly competitive markets, cost reductions are typically captured by consumers directly in the form of lower prices, which increases consumer surplus.[22] Cost reductions captured by producers tend to fall directly to the bottom-line income, all things equal.[23] For technology that facilitates new business models that dramatically alter the cost structure of a product or service, the total economic value, including both the revenue from the new market and the increase in consumer surplus, could be a useful measure to understand the totality of the economic impact, where a large portion may not be observable through market prices. Over-the-air (OTA) updates are a good example of cost reduction primarily from the producer's perspective while ride-sharing is an excellent example of cost reduction from the customer perspective that together with a new business model has disrupted the taxi industry.

2. **Indirect value creation** - this refers to the additional value that is captured by a firm through adjacent products and services or separate markets. An example of an adjacent product effect is customer service regarding vehicle maintenance that can indirectly impact brand loyalty, which leads to an increase in customer retention at the time of new vehicle purchase. Alternatively, an adjacent market effect is prevalent in multi-sided markets where one side of the market is subsidized to increase the value of the other side and thus maximize total revenue (TR). Advertisement-based business models such as those employed by Facebook and Google are typical examples.

Table 3.1 below summarizes the relationship between value logics, value models, and the associated economic measurements that best quantify the value of technology in each context. For technology improvements, the VIU of technology is relative to the added value of the improved products or services and the associated change in consumer surplus. For a technology that enables new products and services or new business models and markets, the VIU of technology is proportional to the total economic value created, including the total

[22] In imperfect markets, consumer cost savings can be captured as producer revenue as well.

[23] In addition, cost reduction technology can be used to lower market prices (p) and therefore capture more significant market share, which would be measured as an increase in total revenue (TR).

market revenue and associated consumer surplus, externalities notwithstanding. As enabling technologies, such as connectivity standards, not only enable products and services but often entire markets, it is appropriate to value these technologies based on the total economic value generated.

Value Logic	Direct Value Model	Economic Measurements
Improved products/services	Revenue generation Cost reduction	Increase in price/quantity Decrease in producer/consumer costs
New products/services or business models/markets	Revenue generation Cost reduction	Total economic value Total economic value

Table 3.1. Summary of the relationships between value logics, direct value models, and economic measurements.

3.3 Valuation Methods

This section will describe several valuation methods typically used to quantitatively determine the value of technology in relation to products and services sold on a market - hedonic pricing, conjoint analysis, and the income method. The latter will be expanded to the value models discussed in the section above.

Hedonic Pricing Method

Hedonic pricing method, based on the consumer theory of revealed preferences, posits that the value of products and services can be broken down into key constituent characteristics. Hedonic pricing can thus be used to disentangle the "shadow" prices of different characteristics separate from the whole. This is typically done in practice by applying regression analysis to a sufficiently large sample of products that exhibit heterogeneous characteristics to reveal the value of the preferred characteristics based on actual market prices. This method has been used in many contexts, including technology-based products, such as personal computers (Pakes, 2003), in automotive (Andersson, 2005), and mobile phones (Sidak & Skog, 2019), among others. With regards to the value of automotive connectivity, the hedonic pricing method could be helpful to understand better consumer preferences regarding the value of connectivity for vehicles in general as well as across different connected vehicle applications that are currently available. As connectivity becomes standard equipment in vehicles, the method could also be helpful to understand the technology's impact on quality-adjusted prices as an estimate of the contribution of connectivity to the price of a vehicle but also its contribution to consumer surplus.[24] At present, the author is not aware of a study using this method with regards to automotive connectivity.

Conjoint Analysis

Conjoint analysis is also based on the consumer theory of revealed preferences but is instead based on consumer surveys about future preferences. Green et al. (2001, p. S57) describes conjoint analysis as "a technique for measuring trade-offs for analyzing survey responses concerning preferences and intentions to buy, and it is a method for simulating how consumers might react to changes in current products or new products introduced into an existing competitive array." In practice, conjoint analysis uses statistical techniques to evaluate consumer choices across an array of the product or service attributes. When combined with pricing information, the method can be used to estimate the consumer's willingness-to-pay (WTP) for specific attributes. This method is a standard tool for market research worldwide.[25] As the value of connectivity in automotive applications is related to the total economic value generated, including consumer surplus, information on consumer's WTP is pertinent to the calculation of value.

In relation to automotive connectivity, numerous management consultants and market research organizations have conducted WTP analysis using consumer surveys (Accenture, 2016; Deloitte, 2017; IHS Markit, 2017, Deloitte, 2019) and conjoint analysis (Simon Kucher & Partners, 2016). These results are investigated further in section 5.1 concerning the direct and indirect impact of automotive connectivity on consumer value, in particular, consumer surplus.

DCF Method

The discounted cash flow (DCF) method is an income-based valuation approach that is useful for the valuation of assets whose value is based on future cash flows. The main components

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[24] See, for example, the early work in the automotive industry by Griliches (1961).

[25] Green et al. (2001)

are cash flow (CF), time (t), and risk (i), whereby future cash flow forecasts are discounted into an aggregate net present value (NPV) as shown in equation 1 below.

$$\text{NPV} = \sum_{t=1}^{n} \frac{CF(t)}{(1+i)^t} - I_0 \qquad (1)$$

CF = cash flow

I_0 = Initial investment

i = risk-adjusted discount rate

t = time over which the cash flows occur

In the context of automotive connectivity, where the focus is on future cash flows associated with specific connected vehicle application, the present value of the key variables that determine operating profit (π) is most relevant. Equation 2 below defines the key variables linked to the value models and economic measurements described in table 3.1 above.[26]

$$\Pi = TR - TC = q^*(p - c) \qquad (2)$$

Π = Operating profit

TR = Total Revenue of goods sold (q*p)

TC = Total Costs of goods sold (q*c)

q = quantity sold

p = price per good

c = costs per good

Thus, from equation 2 above the key economic levers that affect value include the following:[27]

- Increase in demand (Δq)
- Increase in price (Δp)
- Decrease in costs (Δc)

[26] The operating profit is described on the level of the product/service for a firm.

[27] On the market level, the economic levers would be Demand (Q), Price (P), and Costs (C).

The principles of the DCF method can be used in different economic contexts, including the market level, the firm level, and product/service level. In this study, when the vehicle level is investigated, total revenues (TR) will be measured for the entire market across total market demand (Q) to determine applicable average total revenues per vehicle over time. While profit estimates will be presented, the present value (PV) of total revenue (TR) and total costs (TC) will primarily be used to measure the applicable unit of analysis.[28]

4. Connected Vehicle Market, Applications, and Value Models

This section explores the nature of the connected vehicle market, including specific applications and their associated value attributes and models concerning the competing vehicle and mobile ecosystems.

4.1 Economic Value and Competing Ecosystems in the Connected Vehicle Market

Figure 4.1 below provides a simple illustration of the total economic value of connectivity in the automotive sector, including the total market revenue of all relevant commercial activities in the value chain together with the total consumer surplus generated by the connectivity-enabled products and services. The total market revenue can be broken down into two main market ecosystems: the vehicle ecosystem and the mobile (smartphone) ecosystem. Both of these ecosystems share a common upstream value chain from a technology, infrastructure, component, and operator perspective, but each seeks to separately capture the added value of connectivity-enabled automotive services within its own ecosystem. For the mobile ecosystem, this includes the iOS and Android platforms and their associated applications, such as ride-hailing and navigation. For the vehicle ecosystem, this includes the vehicle OEMs and service providers that deliver specific applications, such as insurance companies and municipalities.[29] Across both ecosystems, there is an ongoing competition among vehicle OEMs, mobile platforms, and 3rd party service providers to capture the value of the emerging automotive connectivity market.

[28] This also facilitates the linkage of value at the economic and market level with the value creation at the product/service level to reinforce the understanding of how value is created and distributed in the economy.
[29] Services in the vehicle ecosystem can be bundled and offered through vehicle OEMs, or offered as stand-alone services.

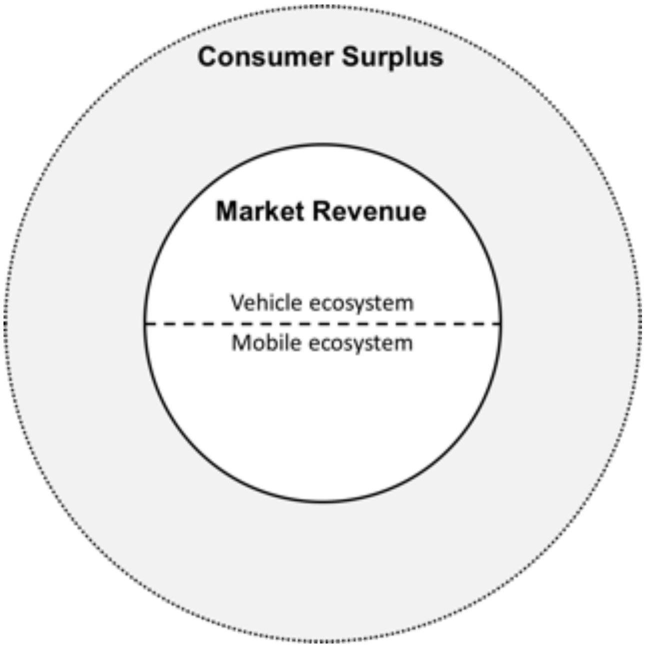

Figure 4.1. Model of total economic value of the connectivity in the automotive sector

4.2 Value Attributes of Connected Vehicle Applications

Connected vehicle services encompass a broad cross-section of growing interrelated value propositions for consumers, manufacturers, and commercial actors, including convenience, safety, security, time-savings, cost savings, entertainment, comfort, and vehicle management features among others. The added functionality of each successive standard generation of connectivity (e.g. 3G-4G-5G) has enabled the development of new connected car applications and the growth of previous applications. In table 4.1 below are listed a number of connected vehicle applications enabled primarily by cellular technology that are currently available on the market as well as several emerging applications. The development of 5G technology will further open up new sources of value, particularly in relation to V2X and autonomous driving applications. While current connected vehicle applications can be viewed as providing primarily complementary value to the main automotive value proposition, this distinction will likely fade as the automotive industry continues to transform into a mobility industry, where connectivity is an essential component. Thus, one could expect the value of connectivity in general, and cellular connectivity in particular, to increase both in terms of complementary services and eventually as the core functionality of what will define mobility in the future.[30]

[30] McKinsey (2019) states "regardless of the type of communication, ubiquitous connectivity is the key to facilitate automation and autonomy among the cars on the road."

Application/ Use case	Primary Ecosystem	Actor Focus	Value Proposition	Value Model
Advanced Navigation	Mobile Vehicle	Consumer	Convenience	Revenue
Breakdown Assistance (bCall)	Vehicle	Consumer	Safety Convenience	Revenue
Emergency Assistance (eCall)	Vehicle	Consumer	Safety	Revenue
Fleet Management[31]	Vehicle	Commercial	Cost savings	Cost
In-Vehicle Hotspot	Vehicle	Consumer	Convenience Entertainment	Revenue
Remote Diagnostics/ Maintenance	Vehicle	Consumer Producer	Cost savings Convenience Loyalty	Revenue Cost Indirect
Shared Mobility	Mobile	Consumer	Convenience Cost savings	Revenue Cost
Usage-Based Insurance	3rd Party	Commercial Consumer	Risk reduction Cost savings	Revenue Cost

Table 4.1 Connected vehicle applications and key value characteristics. Primary Ecosystem = Vehicle, Mobile, 3rd party. Actor Focus = Consumer, Producer, Commercial, and Governments. Value Model = revenue, cost, indirect

The goal of table 4.1 above is neither to be exhaustive nor exact but to provide an understanding of the diversity of the key value characteristics across several connected vehicle applications.[32] This diversity explains not only the challenge in capturing the potential value enabled by connectivity but also in merely understanding the complexity regarding which value propositions are created and for whom.

[31] Fleet management can relate to many types of vehicles, including heavy trucks.
[32] See McKinsey (2018) for a list of 32 potential connected vehicle use cases.

Furthermore, the heterogeneity of applications, actors, and value propositions opens up for a diversity of business models. For example, convenience-based value propositions towards consumers can generate revenue through direct monetization models or multi-sided markets based on advertising or exchange of data. However, cost-saving propositions can impact the consumer, the producer, or both, where control of data is often critical.

5. Quantification of the Value of Automotive Connectivity

The previous sections have defined the fundamentals of economic value and valuation and the scope of automotive connectivity applications. This section will present the quantification of the value of automotive connectivity based on publicly available data from several perspectives, including the entire automotive connectivity value stack, the total market revenue, the vehicle ecosystem, and specific applications. The main focus will be on value generated by automotive products and services that are enabled by cellular connectivity or equivalent technology standards.[33] The goal of this section is to exemplify key valuation concepts and models across different contexts of automotive connectivity with available quantifiable data and growth forecasts to better understand the nature of this emerging market.

5.1 The Economic Value of Automotive Connectivity

Section 3.1 outlined a basic set of concepts to understand value from a socio-economic perspective, including total market revenue/value, total economic value, and net social value. In this section, these concepts will be further elaborated and illustrated using publicly available information to provide an overview of size, growth, and impact of automotive connectivity from a top-down perspective.

5.1.1 The Automotive Value Stack

Figure 5.1 below presents a simple model of the automotive connectivity value stack, which includes key revenue pools in the value chain that are priced in the market, in addition to the consumer surplus and externalities that are not priced but still deliver significant socio-economic value. The bottom layers of this automotive stack (i.e. the communication value

[33] The valuation of cellular-enabled automotive connectivity is also applicable to the valuation of technology substitutes on the market level.

chain) is shared with the mobile industry, in particular, the core communication technologies, the communication infrastructure, and operator connectivity access, and the automotive connectivity system, where the latter can be enabled through an embedded device, a tethered device, or a smartphone. The application layer, built primarily on software and data, provides customized automotive services, as discussed in section 4. The layers from core communication technologies to automotive applications constitute different revenue pools in the total automotive connectivity market where market prices are observable as denoted by Total Market Revenue/Value in Figure 5.1. For comparative purposes, a study by BCG in 2014 estimated the total market revenue for the mobile value chain at approximately $3.3 trillion.[34]

The top two layers of the value stack in figure 5.1 represent value that is outside of the market pricing mechanism - consumer surplus and externalities. Innovation and market competition are continually lowering the quality-adjusted prices and widening the gap between consumer's willingness-to-pay (WTP) and market prices, which results in a growing increase in consumer surplus over time. For example, the same BCG (2014) study mentioned above also estimated the consumer surplus in the mobile value chain in the six countries studied to be approximately $6.4 trillion. As for externalities, one could see the prolific use of cars in society as producing a negative externality through pollution, accidents, etc. whose cost is borne by society as a whole, while concomitantly, the use of connectivity solutions that reduce pollution would produce a positive externality (or reduction in a negative externality).[35]

[34] See BCG (2014).

[35] Attempts to capture environmental externalities through market prices include fuel or carbon taxes on the cost side and subsidies and marketing on the revenue side.

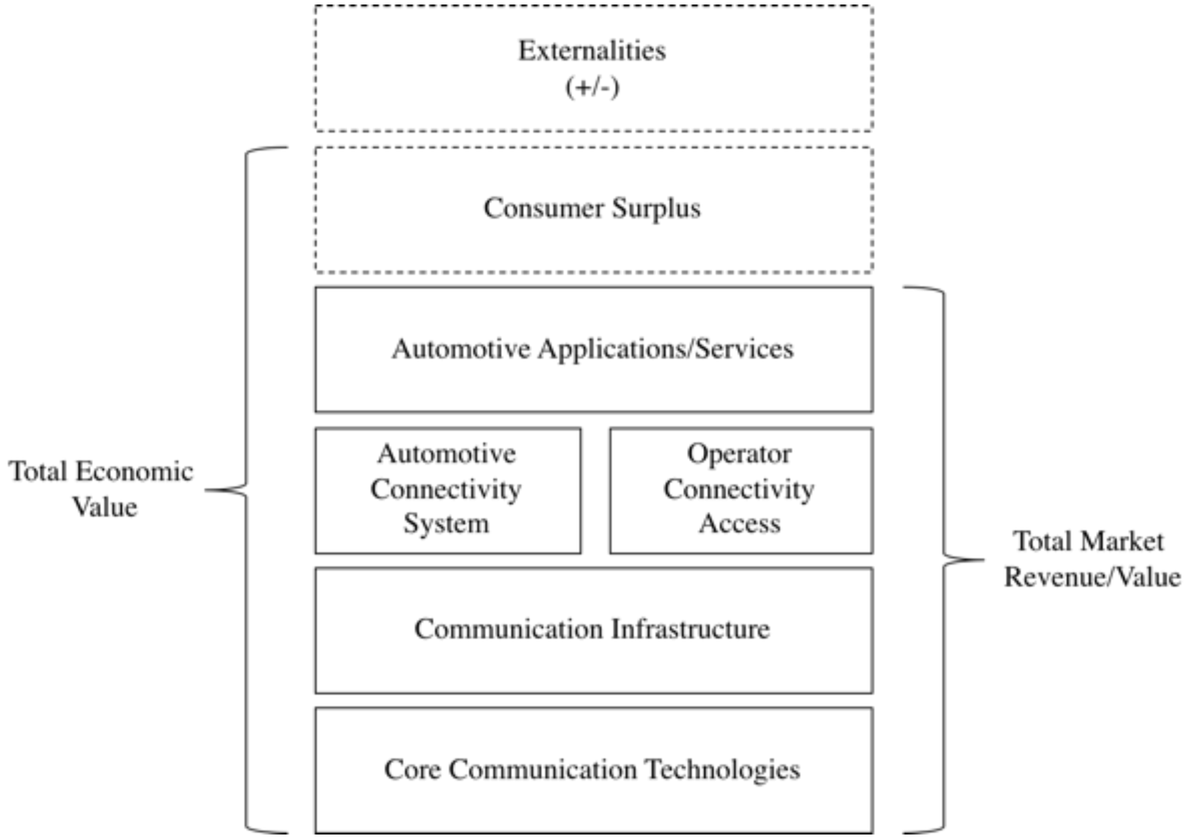

Figure 5.1 Automotive connectivity value stack. Adapted from BCG (2014)

In 2017, Bosch released the findings from their forecast of the socio-economic impact of connected vehicles by 2025. Table 5.1 below displays their findings in relation to the nature of how the value from the specific impact is distributed in society (i.e. will it be captured as revenue in the automotive market or distributed to consumers or society outside of the market?).[36]

Socio-economic impact	**MR**	**CS**	**EX**
Over 260,000 accidents avoided resulting in • 350,000 fewer people injured • €4.43 billion in damages saved	x	x	x

[36] It should be noted that new connectivity-based business models can capture consumer surplus and convert it into market revenue (or producer surplus) through market segmentation and price discrimination, which has become easier through customized digital solutions.

Approx. 11,000 lives could be saved	x	x	x
Nearly 400,000 tons of CO2 avoided			x
Approx. 70 million driving hours saved	x	x	
Up to 31 hours of free time on the highway	x	x	

Table 5.1 Examples of socio-economic impact from connected vehicles
in the USA, China, and Germany by 2025.
MR=Market Revenue, CS=Consumer Surplus, EX=Externality
Source: Bosch (2017), Author's analysis

As one can see from table 5.1 above, there are substantial savings in lives, injuries, and pollution that represent real value for individuals and society but may not always be able to be internalized as a revenue stream in the market (e.g. through an emergency call application). These positive externalities (or reductions in the negative externalities of the use of automobiles in society) may spill over to the common good or be captured in other adjacent markets. In addition, the value of hours saved could be monetized through a time-saving app or in the price of a connectivity device, but it could be transformed into consumer surplus through innovation and competition.[37] Reductions in accidents produce many different effects that may be captured through insurance applications, but will likely create surplus value for consumers and society. As connectivity becomes ubiquitous with road safety, there may be a challenge to price this privately as safety is both a private and public concern that involves government regulation/mandates, such as seatbelts and airbags. This may explain the rationale behind the recent emergency call (eCall) regulation in the EU.[38] While all of these benefits may not be possible to measure at a high level of specificity or certainty, it is clear that they generate added value enabled by connectivity.[39]

One way to better understand the direct and indirect impact of connectivity on consumer demand for products, services, and features, both current and future, is through surveys and conjoint analysis that attempts to gauge the consumer's willingness-to-pay (WTP). Table 5.2

[37] In another example of the potential lost value of time, Roland Berger (2013) estimated that the cost of paralyzed traffic flows in the world's 30 biggest megacities alone adds up to $266 billion.

[38] See https://ec.europa.eu/digital-single-market/en/news/ecall-all-new-cars-april-2018.

[39] For example, health economics has models that can be used to measure the socio-economic value related to injuries and illnesses, including lost time and work in addition to quality of life. This is also related to environmental regulations and governmental spending (e.g. road construction and maintenance).

below highlights the results of several of these studies focused on vehicle attributes and applications related to automotive connectivity.

WTP	Scope	Source
$7,028 per vehicle[40] (€55 per month)[41]	Connected vehicle services Germany	Deloitte (2017)
$1,420 per vehicle	Connected vehicle price South Korea	Shin et al. (2015)
$1,215 per vehicle (3.5% of car price)[42]	Connected vehicle price China, US, Germany	Accenture (2016)
$840 per vehicle (US) €400 per vehicle (DE)	Connected vehicle price US, Germany	Simon Kucher & Partners (2016)[43]
$201 per vehicle[44]	Connected vehicle price US, CA, UK, CH, DE	IHS Markit (2017)

Table 5.2. Studies on consumers' willingness-to-pay (WTP) for automotive connectivity

The research results of the different studies above show a broad range of average WTP estimates from $201-$7,028 at the point of sale for a connected vehicle. Generation Y respondents in Germany indicated that they would be willing to pay €55 per month corresponding to approximately $7,000 over the average lifetime of a vehicle.[45] One can compare this number to the market prices of premium connectivity services offered by automakers in figure 5.2 below, which shows a heterogeneous set of prices ranging from $330-$22,645 corresponding to an average of approximately $3,900 per vehicle over its

[40] Calculated based on the NPV of a constant €660 per year for 11 years discounted at 4.6%. 1 EUR = 1.2 USD (2017).

[41] Corresponds to Generation Y respondents.

[42] Based on the willingness of 71% of respondents (from China, US, and Germany) to pay up to 10% of the vehicle price for desired connectivity capability.

[43] Removing the methodological constraint of fixed pricing scenarios in the exercise, increased the average spend for connectivity to €440 in Germany and $1,070 in the U.S.

[44] Based on WTP per region for surveyed consumers that showed interest in telematics (32%) and In-vehicle hotspot (29%). The WTP for both has been combined.

[45] This sum represents all required costs, including a mobile subscription

lifetime.[46] The difference between what consumers are willing-to-pay and the actual market prices (i.e. willingness-to-sell) provides one indication of the amount of consumer surplus in the automotive connectivity market. The variation in WTP studies and automaker prices is an indication that the value of connectivity is highly contextual across different consumer segments and automakers.

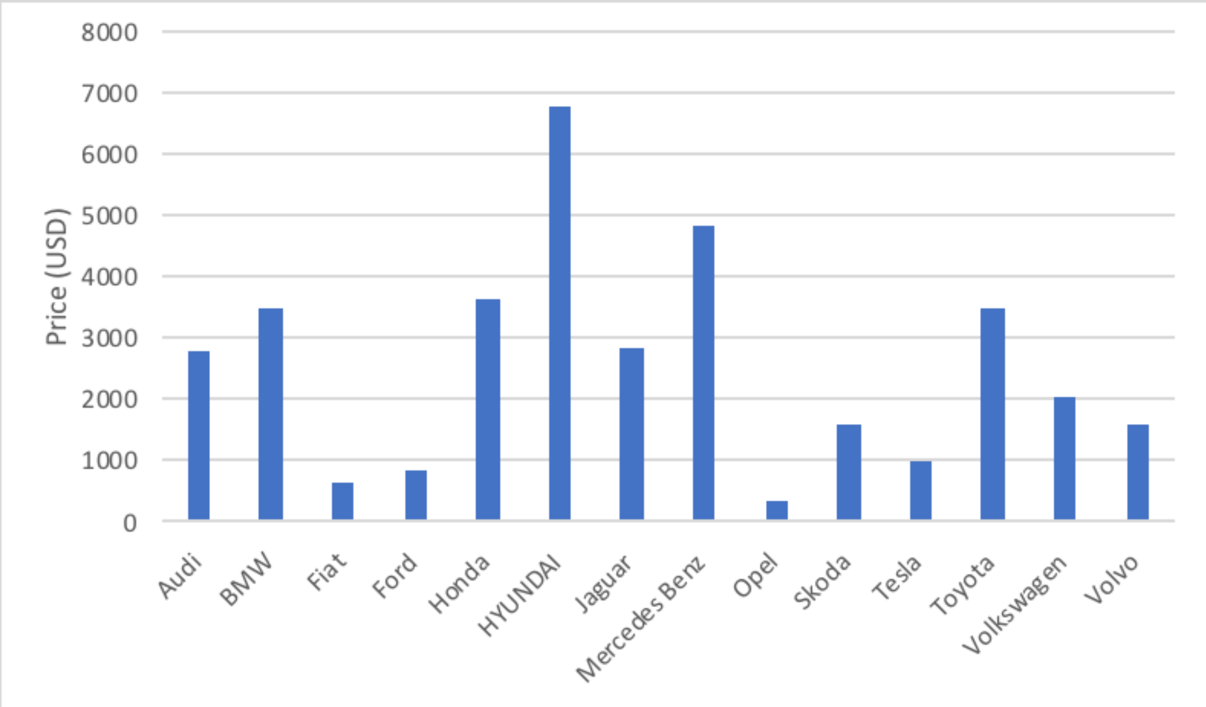

Figure 5.2 Cumulative prices for premium connectivity services per automaker (2019). Source: Arya (2019)

Deloitte (2019) looked further into the consumers' WTP and found that applications that generate time savings are most desirable, followed by safety applications.[47] McKinsey (2018) found similar results, adding that over 90% of respondents in all countries surveyed (China, US, and Germany) preferred to trade their data in return for connectivity services, including time savings, safety, convenience, and cost savings applications. Thus, the potential for multi-sided markets that trade data for services makes it challenging to measure the value of connectivity only from direct market revenue. Indirect value, externalities, and consumer surplus all need to be considered to understand the overall value of automotive connectivity

[46] The pricing of connectivity services was obtained through public sources and a survey completed by automakers.

[47] These results were consistent across multiple countries, including Germany, US, China, India, Japan, Republic of Korea.

from an economic or societal perspective even though market revenue is the easiest to observe. The latter will be discussed from a holistic perspective in the next section.

5.1.2 Total Market Revenue

As defined in section 3, the total market revenue for automotive connectivity includes both the vehicle ecosystem and the mobile ecosystem, which are captured in the shaded areas of figure 5.3 below, namely the automotive connectivity system and the automotive applications/services. From an investigation of the publicly available data, market revenue estimates tend to focus on these revenue pools, in particular, revenue from vehicle connectivity hardware and specific services or bundles of services through either the vehicle hardware or a mobile device or both. Typically, neither the mobile device nor the operator subscription, for the vehicle or mobile device, appear to be included in the market revenue data. The communication infrastructure and core technologies, which is currently a shared network resource, is also not included in the automotive market data but can be found in the mobile market data.[48] Thus, the total revenue for the automotive connectivity market is primarily based on an estimate of the revenue from vehicle connectivity hardware and the combined revenue from vehicle and mobile-based automotive services. A subset of total revenue-focused primarily on the revenue generated by the vehicle ecosystem segment can also be found. Studies that have estimated both the total ecosystem and vehicle ecosystem revenue will be discussed further in this section.

[48] See BCG (2016) for a breakdown of the mobile market revenue pools.

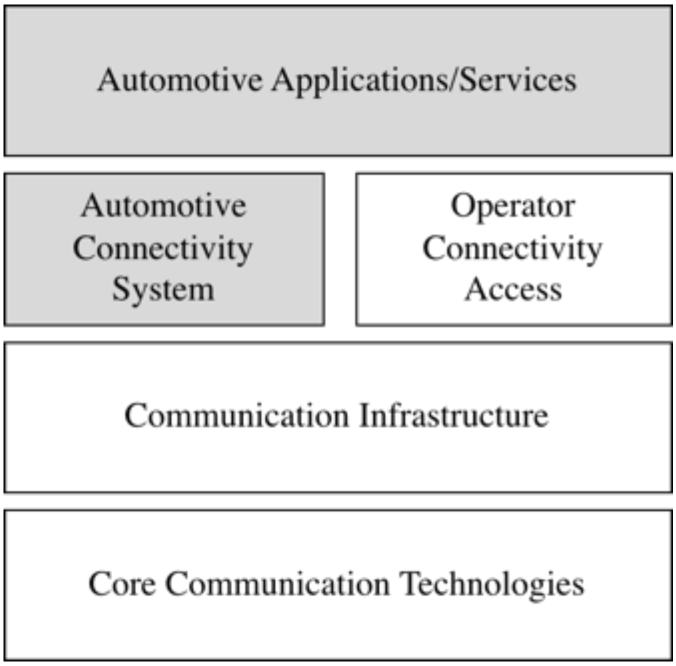

Figure 5.3. Total market revenue segment of the automotive connectivity value stack

Given the importance of connectivity in the transformation of the entire automotive value chain, many actors have investigated the automotive connectivity market and developed forecasts of its growth. Forecasts are necessary for this context, given the transformational nature of the industry that is predicted to undergo exponential growth in the coming decade. However, as connectivity is an enabling technology that touches on most aspects of mobility and associated vehicular services, the challenge is to understand the underlying context and assumptions of the forecasts that are available in the public domain. This is especially true given the number of current and potential applications (e.g. see section 4) as well as the possibility to separate B2C and B2B applications across both the vehicle and mobile ecosystems. Thus, this section will present several forecasts as reported and attempt a comparative analysis that considers both the uncertainty of the future and heterogeneous scope of the revenues in the forecast.

Forecast	Scope	Forecast Year	Source
$31 billion	Vehicle Ecosystem	2023	Statista (2019)
$24 billion[49]	Vehicle Ecosystem	2025	Counterpoint (2019)

[49] https://www.counterpointresearch.com/connected-car-revenues-grow-five-fold-2025/

$350 billion	Total Ecosystem	2020	Ptolemus (2016)
$253 billion	Total Ecosystem	2025	Machina Research (2017)[50]
$660 billion[51]	Total Ecosystem	2025	Deloitte (2017)
$832 billion[52]	Total Ecosystem	2025	Accenture (2016)
$2,000 billion[53]	Total Ecosystem	2030	McKinsey (2018)

Table 5.3. Revenue forecasts for the automotive connectivity market. All forecasts are global.

The forecasts in table 5.3 above represent estimates of total revenue for a subset of automotive connectivity applications for the total ecosystem (vehicle and mobile) and the vehicle ecosystem only. It is clear that the total ecosystem forecasts are an order of magnitude greater or more than the vehicle ecosystem revenues. One potential key factor is likely the inclusion of ride-hailing services in the total ecosystem forecasts. To illustrate, figure 5.4 below provides data on current and forecasted revenues for ride-hailing services worldwide from 2017-2023 that is typically not included in vehicle ecosystem estimates. The ride-hailing revenue ranges from about $128 billion in 2017 to a forecast of around $320 billion in 2023. McKinsey (2018) forecasts the shared mobility segment at $1.4 trillion by 2030, roughly 20% of the total worldwide automotive market of $7.2 trillion in 2030. Currently, shared mobility services such as ride-hailing are primarily managed through the mobile ecosystem of the automotive connectivity market. However, in a future of autonomous vehicles, a hybrid ecosystem would develop between consumers with mobile devices and vehicles with embedded devices, which shows the dynamic nature of the market and the potential for redistribution of revenue across a value chain and between the vehicle and mobile ecosystems that are under reconstruction.

[50] The results of Machina Research (2017) as presented in GSMA (2019).

[51] Based on a simulation of hypothetical car company starting with €60 in revenue in 2015 under the scenario where connectivity, e-mobility, autonomous driving, and integrated mobility become the norm.

[52] Based on a forecast of $216.2 billion in China, representing 26% of the global market.

[53] Based on a forecast of revenue from shared mobility ($1,400 billion) and car data-enabled services ($450-750 billion).

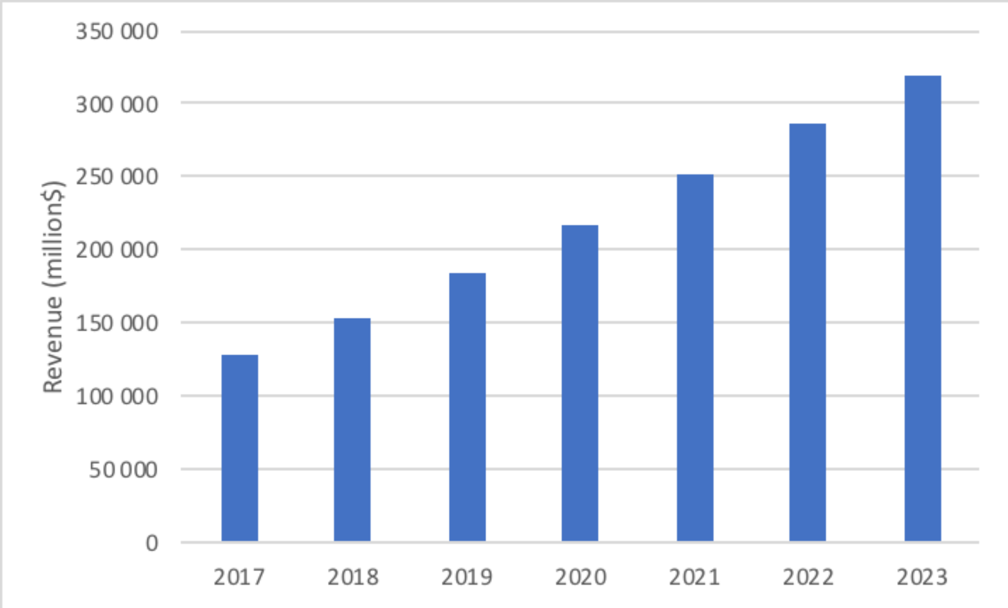

Figure 5.4 Ride-hailing service revenue worldwide from 2017-2023. Source: Statista July, 2019.

Table 5.4 below provides an overview of the total revenue of the automotive connectivity market for the total ecosystem based on data for a subset of mutually exclusive automotive applications for 2018 and 2023.

Revenue pool	**2018**	**2023**
Vehicle hardware	17,511	27,901
Vehicle services[54]	885	2,335
Infotainment services[55]	346	1,284
Usage-Based Insurance (UBI)[56]	15,620	65,342
Smart parking[57]	17,800	35,800

[54] This includes applications for safety and security, maintenance and diagnostics, and remote services.

[55] This includes applications for advanced navigation and comfort services.

[56] The 2023 revenue forecast was calculated based on a linear growth model from the two point estimates from 2018 to 2027.

[57] The 2018 and 2023 revenue forecasts were calculated based on a linear growth model from the two point estimates from 2015 to 2025.

Fleet management services[58]	16,756	31,636
Ride-hailing	153,591	318,765
Total	**222,509**	**483,063**

Table 5.4. Current and forecasted revenues for the automotive connectivity market (millions$). All forecasts are global. Source: Statista

5.2 Total Revenue per Connected Vehicle

In this section, the total revenue per vehicle (TR) from automotive connectivity will be estimated based on publicly available market data. The total revenue per vehicle shown below in equation 3 is determined by adding the increase in vehicle revenue due to connectivity at point of sale (ΔVR_0) with the net present value of the summation of all connectivity service revenue (SR) across all applications over the life of the vehicle.

$$TR = \Delta VR_0 + \sum_{t=1}^{l} \sum_{a=1}^{n} \frac{SR_{at}}{(1+i)^t} \qquad (3)$$

TR = Total revenue (per vehicle)

ΔVR_0 = Increase in vehicle revenue due to connectivity at point of sale

SR = Service revenue (per vehicle)

t = time

l = life time of the vehicle

a = connectivity applications

n = total number of applicable connectivity applications

i = discount rate

5.2.1 Total Revenue per Connected Vehicle in Vehicle Ecosystem

Figure 5.5 below shows the revenue for connected cars, including connected hardware, vehicle services, and infotainment services from 2017-2023 on a worldwide basis.[59]

[58] The 2018 and 2023 revenue forecast was calculated based on a linear growth model from the two point estimates from 2017 to 2022.

[59] Statista, March 2019. Connected hardware represents the one-time purchase of hardware that enables vehicle connectivity. Vehicle services are limited to maintenance and diagnostic applications, and infotainment services are limited to navigation and media streaming applications. In comparison, McKinsey (2014) estimated

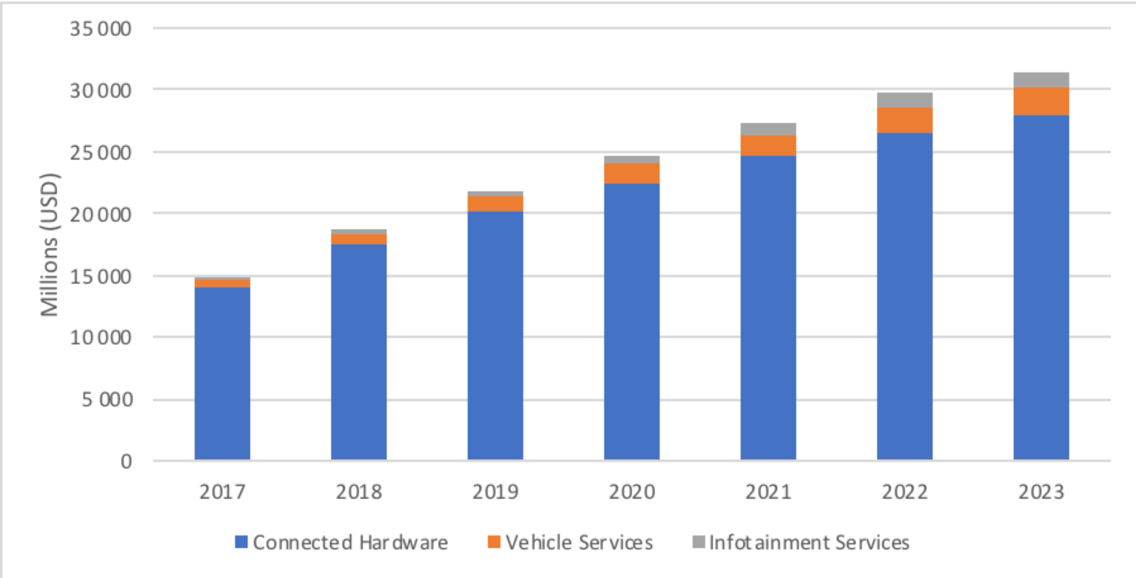

Figure 5.5. Revenue in the connected car market (worldwide)

In order to estimate the total revenue per vehicle (TR) using equation 3 above, the number of new connected vehicles and the total stock of connected vehicles is required. Table 5.5 below shows the data and calculations used to determine the estimation.

Data	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Stock of connected cars (million)	86,8	119,4	157,9	201,0	248,2	299,2	352,9
New connected cars (million)		32,6	38,5	43,1	47,2	51,0	53,7
Total Hardware Revenue (million$)	14 014	17 511	20 230	22 527	24 627	26 597	27 901
Total Service Revenue (million$)	846	1 231	1 664	2 132	2 627	3 142	3 619
Total Revenue (million$)	14 860	18 742	21 894	24 659	27 254	29 739	31 520
Calculations							
Total Hardware Revenue per car ($)		537	525	523	522	522	520
Service Revenue per car (NPV$)		10	10	10	9	9	8
Total Service Revenue per car (NPV$)		56					
Total Revenue per car (2018$)		593					

Table 5.5. Calculation of estimated total revenue per connected car in 2018. Source: Statista, March 2019. Calculations: Author

Since the total revenue per vehicle has both a current and future component, a single year, 2018, was chosen to provide an estimate using the available data. The calculation of the increase in vehicle revenue due to connectivity at the point of sale (ΔVR_0) was found to be $537 per connected vehicle[60], and the net present value of the total service revenue amounted

that the global revenue for automotive connectivity hardware in 2014 was approximately €29 billion, which is more than twice as much as shown in the Statista research for 2017.

[60]. This was calculated by dividing the total hardware revenue by the number of new connected cars entering the market in 2018.

to $56 per connected vehicle in 2018.[61] The total revenue per connected vehicle based on the worldwide market in 2018 is estimated at $593. A similar calculation of the US market yielded an estimate of $670.[62] It is important to recognize that the above estimates are an average across all new and existing connected vehicles, so the revenue potential across different vehicle makes and models can vary as well as across different types of connectivity (e.g. 2G, 3G, 4G, etc.). An estimate of revenue per connected vehicle for General Motors specifically will be investigated in the next section.

Table 5.6 below provides additional estimates of total revenue per connected vehicle from other public information sources in comparison to the calculations above.

Forecast (per vehicle)	Scope	Forecast Year	Source
$670 revenue (US) $593 revenue (WW)	Vehicle Ecosystem	2018-2023	Statista (2019)
€2,240 revenue (DE) €3,920 revenue (DE)	D-segment, premium vehicle, Germany[63]	2014-2019 2020-2025	McKinsey (2014)
$680 revenue (US)	Vehicle Service Ecosystem	2011	Cisco (2011)

Table 5.6. Studies of total revenue per connected vehicle.

5.2.2 Total Revenue per 4G-enabled Vehicle in GM Onstar Ecosystem

In April 2015, the CFO of General Motors, Chuck Stevens, gave a presentation at a Bank of America Merrill Lynch conference where he was quoted as saying that GM's Onstar 4G connectivity was an "untapped, under-appreciated opportunity."[64] He further elaborated that "based on our plans today, which are still in the early stages of really taking advantage of this

[61] This was calculated by discounting the six years of service revenue from 2018-2023 (*l*=6). The service revenue was calculated by dividing the total service revenue per year by the stock of connected cars. A discount rate (*i*) of 4.6% was applied based on the average automotive industry cost of capital - see http://people.stern.nyu.edu/adamodar/New_Home_Page/datafile/wacc.htm

[62] The data from Statista is focused on the vehicle ecosystem and does not include B2B services.

[63] Based on average customer spending over the 5-year life cycle in the D-segment, premium vehicle, Germany. The revenue forecast for 2020 included the following as connected hardware with approximate revenue per connected car in parentheses: navigation (€1,440), smartphone integration (€560), entertainment (€200), remote services (€440), and ADAS (€830). The projected services included navigation (€270), apps (€70), and entertainment (€140).

[64] See https://www.reuters.com/article/us-gm-cfo/gm-to-earn-350-million-over-three-years-from-4g-technology-in-cars-cfo-idUSKBN0MS4NS20150401. See also General Motors, From 8-K, April 1, 2015, slide 15.

technology, we expect to see $350 million of profit improvement between now and 2018 specific to 4G LTE, and in our view, that's just the beginning."[65] A few weeks later, the Auto News announced that IHS analyst, Mark Boyadjis, had estimated the increased profits to GM from 4G at approximately $439 million over the following three year period, adding that lower warranty costs due to high-speed connectivity could dwarf that amount.[66] In June 2015, Egil Juliussen, director of research and principal analyst for IHS Automotive Technology Group estimated that GM could generate $394 million in revenue through US data subscriptions in 2018 alone based on its 1.9 million US 4G LTE subscribers.[67]

Table 5.7 below shows the data and calculations used to determine the estimation of the total revenue per 4G enabled GM vehicle based on the above forecasts for the period 2016-2018.[68]

Data	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Stock of 4G vehicles (million)	0,63	1,26	1,9					
GM CFO income forecast (million$)	58	116	175					
Average income per vehicle per year ($)	92	92	92					
Calculations								
Service Income per vehicle per year (NPV$)			92	88	84	80	77	73
Total Service Income per vehicle (NPV$)			495					
Total Service Revenue per vehicle (NPV$)			1522					

Table 5.7. Calculation of estimated total service revenue per 4G-enabled GM vehicle in 2018.
Calculations: Author

Since GM Onstar employs a subscription-based business model, the forecast by the GM CFO is assumed to cover the recurring service income and not include the one-time income for connectivity as the point of sale (i.e. ΔVR_0 is not included).[69] Thus, the calculation will be for total service revenue per vehicle (TSR), not total revenue per vehicle (TR).

In order to estimate TSR, the total stock of 4G-enabled GM vehicles in 2016-2018 is required. Based on a forecast for 2018 of 1.9M 4G-enabled GM vehicles in the US, a linear growth model was used to determine an estimated total stock from 2016-2018.[70] A similar linear

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65 Ibid.

66 See https://www.autonews.com/article/20150417/OEM06/150419879/gm-counting-on-high-speed-internet-services-in-car-to-drive-profits.

67 See https://www.detroitnews.com/story/business/autos/general-motors/2015/06/18/gms-connection-boost-consumer-features-revenue/28964127/.

68 The 2016-2018 period was chosen although the forecast by GM was made in Q2 of 2015 to err on the conservative side.

69 See https://www.onstar.com/us/en/plans-pricing/compare-plans/.

70 The total stock of 4G-enabled GM vehicles includes vehicles from 2015-2018.

growth model was employed to the income forecast of $350M over the same period, producing an average income per vehicle per year of $92, resulting in an NPV of $495 over the same 6-year period (i.e. $l = 6$) used in the calculations above in section 5.2.1.[71] The 6-year service period is conservative, given the average age of vehicles on the road is approximately 11 years.[72] Finally, an estimated profit margin of 32.5%[73] was used to convert income into revenue resulting in a TSR of $1,522 based on the official GM forecast assuming the forecast only applied to the US market. If the forecast were based on worldwide sales, a conservative estimate of TSR would yield $634 based on a 58% global share of GM vehicles sold in 2018.[74] Table x. below summarizes the TSR for the three forecasts presented in this section.

TSR	Forecast	Forecast Year	Source
$1,522 per vehicle (US) $634 per vehicle (WW)	$1,077 million[75]	2016-2018	GM CFO (2015)
$1,909 per vehicle (US) $795 per vehicle (WW)	$1,351 million[76]	2016-2018	IHS (2015)
$1,113 per vehicle (US)[77]	$394 million	2018	IHS (2015)

Table 5.8. Comparison of forecasts in relation to the introduction of 4G services by GM Onstar.

It is reasonable to assume that the total service revenue figures in table 5.8 should be much greater for GM Onstar than the worldwide average of service revenue for connected vehicles given Onstar's long service history and the smaller size of the applicable 4G-enabled vehicle market for GM vehicles. It should be reiterated that these calculations are based on forecasts that should now be possible to verify with actual market data from GM.

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[71] A discount rate (*i*) of 4.6% was applied based on the average automotive industry cost of capital - see http://people.stern.nyu.edu/adamodar/New_Home_Page/datafile/wacc.htm.

[72] The average age of the stock of cars on the road in the US and EU is approximately 11-12 years. See https://www.thedrive.com/news/24110/by-the-numbers-average-age-of-americans-cars-higher-than-ever and https://www.acea.be/statistics/tag/category/average-vehicle-age.

[73] Based on an estimated profit margin range of 30-35% - see https://www.autonews.com/article/20130527/OEM/305279958/not-satisfied-with-onstar-s-steady-profits-gm-wants-to-create-a-global-4g-powerhouse.

[74] See https://www.statista.com/statistics/304392/vehicle-sales-of-general-motors-by-region/. This estimate assumes symmetric role-out of 4G-enabled vehicles and services worldwide, which would reduce the average service income per vehicle per year in the estimate in table x.

[75] Represents the revenue equivalent of $350 million based on a 32.5% profit margin estimate at Onstar.

[76] Represents the revenue equivalent of $439 million based on a 32.5% profit margin estimate at Onstar.

[77] Calculated based on the NPV of service revenue per vehicle per year ($439M/1.9M) discounted over 6 years at 4.6%.

5.3 Calculating Value in Automotive Connectivity Applications

In this section, two specific automotive connectivity applications will be investigated, employing different value models to exemplify further how connectivity creates value in the automotive sector. The different value models include revenue generation, cost reduction, and mixed models.

5.3.1 Advanced Navigation

Advanced or connected navigation provides additional features beyond basic GPS-based navigational services through cellular connectivity either embedded in the vehicle or through the use of a smartphone. The value model is based on revenue generation, typically through a subscription model, although advertising-based models are also applicable. For example, GM Onstar's Connected Navigation provides advanced features through its embedded 4G connection, including real-time traffic updates, enhanced voice recognition, real-time points of interests, and predictive navigation.[78] Connected Navigation is available from Onstar as part of their Unlimited Access subscription ranging from $39.99-59.99 per month.[79]

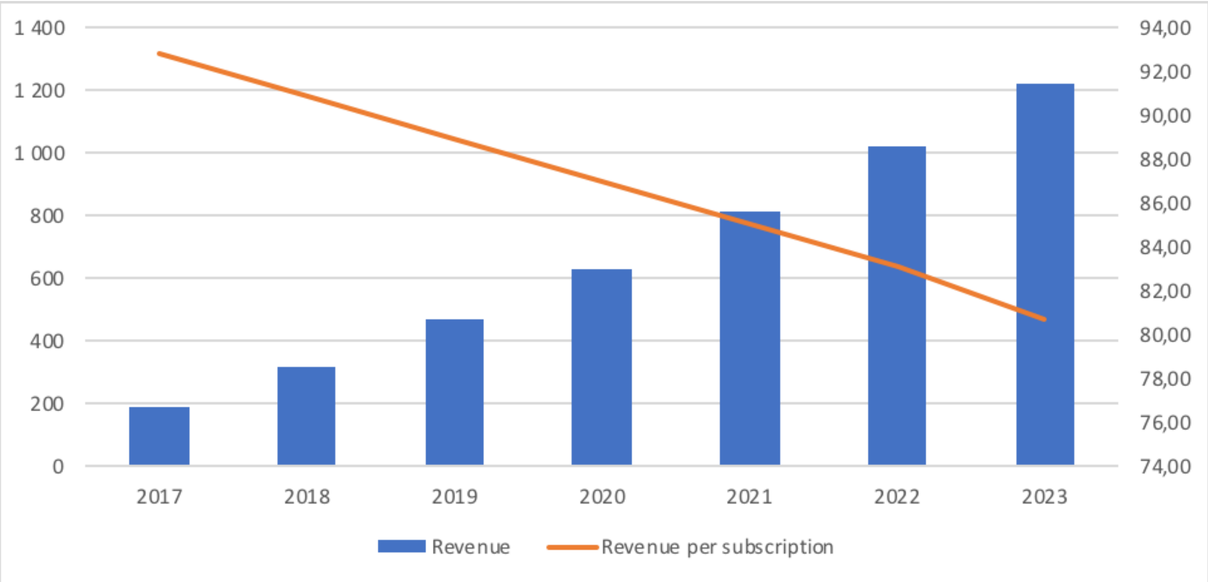

Figure 5.6. Worldwide Advanced Navigation revenue 2017-2023. Source: Statista, March 2019

Figure 5.6 above shows the revenue growth of advanced navigation worldwide from 2017-2023 as well as the revenue per subscription. Equation 4 below describes the method to

78 https://my.gm.com/how-to-support/onstar-connected/features/connected-navigation.

79 https://www.onstar.com/us/en/plans-pricing/compare-plans/.

calculate the total service revenue per vehicle/subscription for a revenue-generating application, such as advanced navigation.

$$\mathrm{TSR} = \sum_{t=0}^{l} \frac{SR_t}{(1+i)^t} \tag{4}$$

TSR = Total service revenue (per vehicle/subscription)

SR = Service revenue (per vehicle/subscription)

t = time

l = life time of the vehicle

i = discount rate

Applying equation 4 to the data shown in figure 5.6 for the 6-year period, 2018-2023 produces an average TSR of $464 based on the NPV of the service revenue per subscription over the time period. The total service revenue per connected vehicle worldwide is $17. The significant difference between $464 per subscription and $17 per connected car is indicative of the currently low adoption rate of advanced navigation services captured by automakers in the vehicle ecosystem.[80]

5.3.2 Over-the-Air (OTA) Updates

The technology share of a vehicle's components is becoming more electronic[81] and their functionality more software-based.[82] This development leads to the opportunity to generate constant upgrades to the vehicle in the same way that customers receive upgrades to their computers and mobile devices. In addition, this will allow for automakers to more quickly and inexpensively solve software related defects (i.e. bugs) that have historically required large recall campaigns that are costly in both terms of money and reputation. In 2018, vehicle electronic/software recalls accounted for 102 total campaigns affecting almost 18 million

[80] One possible explanation slowing adoption of subscriptions could be the competition by advanced navigation provided by mobile applications.

[81] https://www.statista.com/statistics/277931/automotive-electronics-cost-as-a-share-of-total-car-cost-worldwide/

[82] https://www.technologyreview.com/s/508231/many-cars-have-a-hundred-million-lines-of-code/.

vehicles.[83] For example, Mazda recently recalled 262,000 vehicles due to a software problem that caused the engine to stall.[84]

Due to increased automotive connectivity, the use of over-the-air (OTA) software updates, also known as SOTA (software-over-the-air), are now technically possible. In 2018, Tesla, a pioneer in OTA updates, pushed a significant software update to improve the braking performance of the Model 3 after a negative review by Consumer Reports.[85] More companies are now promising OTA updates to their customers as early as their 2020 models, though safety and security challenges exist.[86]

Figure 5.7 below shows the growth of software-based vehicle recalls in the US from 2007-2016, including the number of unique campaigns and total vehicles affected.

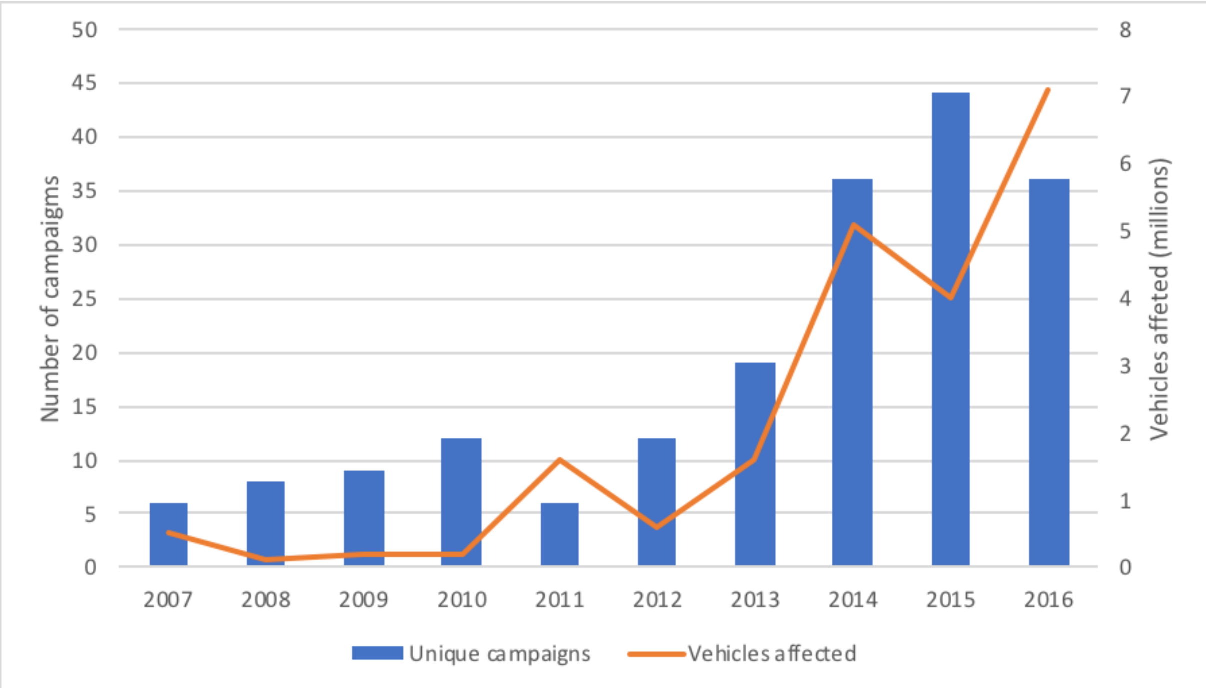

Figure 5.7. Software-based vehicle recalls in the US from 2007-2016.

Source: Stout (2017) with author's approximations.

[83] https://www.recallmasters.com/2018-recalls/.

[84] https://www.consumerreports.org/car-recalls-defects/mazda-recalls-vehicles-because-they-could-stall/.

[85] https://www.wired.com/story/tesla-model3-braking-software-update-consumer-reports/.

[86] https://www.consumerreports.org/automotive-technology/automakers-embrace-over-the-air-updates-can-we-trust-digital-car-repair/.

Vehicle recalls are both expensive for automakers as well as for customers, due to loss of time and convenience, which in turn affects brand loyalty. This creates the opportunity for hybrid business models that both provide OTA updates as a revenue-generating value proposition to the customer as well as an investment in cost reduction technology for the automaker. In turn, this can generate higher customer satisfaction leading to a greater likelihood of further service relations and the repurchase of the same brand.

Equation 5 below describes the method used to calculate the total revenue (TR) derived from applying OTA updates from revenue generation, cost reduction, and indirect effects.

$$\mathrm{TR} = \underbrace{\sum_{t=0}^{l} \frac{SR_t}{(1+i)^t}}_{\text{(revenue)}} + \underbrace{\sum_{t=0}^{l} \frac{\Delta c_t}{(1+i)^t}}_{\text{(cost)}} + \underbrace{\sum_{t=1}^{l} \frac{\Delta R_{Loyalty}}{(1+i)^t}}_{\text{(indirect)}} \qquad (5)$$

TR = Total revenue (per vehicle/subscription)

SR = Service revenue (per vehicle/subscription)

Δc = cost reduction due to OTA updates

$\Delta R_{\text{Loyalty}}$ = revenue generation based on increased loyalty from OTA updates/interaction

t = time

l = life time of the vehicle

i = discount rate

While owners of computers and mobile devices have grown accustomed to free, downloadable software updates, car owners could be charged for OTA upgrades that improve the performance of their vehicle. Currently, Tesla bundles OTA updates into its premium connectivity subscription for approximately $100 per year.[87] In addition, the indirect value through increased customer loyalty could be translated into greater customer retention during repurchase and better adherence to scheduled maintenance. For example, one study found that Toyota's market share was reduced by 0.007% each time the media covered the automaker's

[87] https://www.tesla.com/support/frequently-asked-questions-connectivity.

recalls in 2009 and 2010.[88] However, the most significant amount of value generated by OTA updates will be captured through cost savings to the automaker, as discussed below.

Data	2016
Total vehicles recalled (millions)	29
Software-based recalls (millions)	7,1
Total recall costs (billion$)	22,1
Calculations	
Cost for software recalls (billion$)	5,4
Stock of vehicles (millions)	268,8
Cost for software recall per vehicle ($)	20
Total potential OTA cost savings per vehicle (NPV$)	177

Table 5.9. Calculation of OTA cost savings from US vehicle recalls.
Data Source: Stout (2017), Alix Partners (2018). Calculations: Author

Table 5.9 above applies the vehicle recall data from 2016 to estimate the total cost reduction per vehicle (TCR) that could be saved due to OTA updates. In 2016, software-based recalls represented 24% of the total vehicle recalls that year.[89] The total costs of recalls in 2016 were $22.1 billion.[90] Applying a simple proportional model, the cost for a software recall per vehicle was calculated as approximately $20 in 2016 for a total NPV of cost savings of $177 per vehicle, which could be potential OTA cost savings per connected vehicle.[91] This estimate can be compared to the $100-150 in OTA savings for GM per vehicle over its lifetime predicted by Egil Juliussen, director of research and principal analyst for IHS Automotive technology group, in 2015.[92]

Data	2022
OEM OTA cost savings (billion$)	35
Stock of connected vehicles (millions)	299
Calculations	
OTA cost savings per connected vehicle per year ($)	117
Total OTA cost savings per connected vehicle (NPV$)	1038

Table 5.10. Total OTA cost savings per connected vehicle.
Data Source: IHS Automotive (2015) and Statista (2019). Calculations: Author.

88 Shin et al. (2012).
89 (7.1M/29M). Approximated from Stout (2019).
90 Alix Partners (2018)
91 The proportional model could be questioned as a cost comparison between software, and non-software based recalls have not been investigated. Additionally, the total stock of US vehicles is heterogeneous in terms of the applicability of software-based recalls.
92 https://www.detroitnews.com/story/business/autos/general-motors/2015/06/18/gms-connection-boost-consumer-features-revenue/28964127/

In 2015, IHS Automotive estimated that cost savings due to OTA updates would grow from the present size of $2.7 billion to $35 billion by 2022, focused primarily on telematics and infotainment updates.[93] As most of the potential cost savings will occur in the future as the OTA market matures, table 5.10 above investigates this forecast in further depth, resulting in total OTA cost savings per connected vehicle of $1,038 over its lifetime.[94]

6. Conclusion

This study takes a first look at the actual value that connectivity in vehicles can bring to society and the different sectors affected, resulting in the following key insights:

- Connectivity is a megatrend that is transforming the automotive industry towards a new mobility sector. In the near future, most new vehicles will be increasingly equipped with embedded connectivity capabilities due to safety regulations, development of V2X functionality, and the potential service revenue.

- The growing value of connectivity in the automotive sector is predicated on the development of high performance, open telecommunication standards, such as advanced cellular technology (e.g. 4/5G).

- The vehicle is becoming the next big digital platform, generating competition between the existing mobile/smartphone ecosystem and the emerging vehicle ecosystems for control of the value of automotive/mobility services.

- Connected vehicle applications are still small but are growing. Current estimates of the revenue from the vehicle ecosystem to automakers were calculated at $670 (US) and $593 (WW) per connected vehicle, based on a subset of existing applications in 2018.

- The total revenue from connectivity-enabled products and services in the automotive sector was calculated to grow from $223 billion to $483 billion from 2018-2023 for a subset of existing revenue pools, with forecasts predicting as much as $2 trillion by 2030.

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93 https://www.businesswire.com/news/home/20150903006570/en/Over-the-air-Software-Updates-Create-Boon-Automotive-Market

94 The calculation is based on a constant cost savings of $117 per year over an 11-year vehicle life with a discount rate of 4.6%.

- Market revenues do not provide the whole picture, especially when multi-sided business models are deployed. Therefore, the total economic value, including consumer surplus and relevant externalities, is vital to bear in mind when determining the value of connectivity in the automotive sector or regulation of the sector.

As the automotive sector is in a stage of transformation, the future value of connectivity from the perspective of the emerging vehicle platform will be based on a dynamic set of factors, including among others:

- The growth of connected vehicles
- The growth and adoption of connected vehicle applications, especially V2X and AD/ADAS functionality
- The growth in performance of connectivity standards
- Potential changes in the structure of the market and the choice of business models
- The competition between the vehicle and the mobile ecosystems
- Governmental policies and regulations

These factors will need to be re-examined over time as the industry evolves to better understand the changing contribution of connectivity to the automotive sector. Finally, the distribution of the increasing value that connectivity will bring to the automotive sector is another interesting and important area of future research given the role that connectivity plays as an enabling technology. Future market norms, as well as public policies and regulations, will need to strike the right balance to incentivize both the development of new, advanced connectivity standards and innovative automotive applications that facilitates the generation of value for producers, consumers, and society as a whole.

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