The Business of Electric Vehicles:
A Platform Perspective
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Abstract

Platform business tactics are highly visible and dominant in business today. Prominent firms in industries such as information services, retail, and travel, have embraced platform thinking. Still, many others are engaged in a platform game without realizing it, often to negative consequences. This article develops this theme with an illustrative focus on the battery electric vehicle segment of the automobile industry. It traces the development of the industry, identifies key decisions by various participants, and analyzes these decisions from a platform strategy lens.

We emphasize that platform characteristics and network effects are at the core of the electric vehicle industry. A battery electric vehicle is not just a vehicle whose fuel happens to be supplied by the battery. Rather, the vehicle purchase decision is heavily influenced by the availability of a widespread supercharging network as a complementary good. Hence, it is vital for the vehicle maker to ensure that customers have access to both sides of the market – an exciting vehicle and robust supercharging network. An electric vehicle differs from gasoline-powered vehicles in this regard because the refueling network for gasoline vehicles is already robust, widespread, and interoperable across brands, thereby becoming inconsequential to customer adoption decision and firms' strategy.

For electric vehicles, the two-sided platform nature of the industry underlines the need for a well-coordinated strategy on both sides of the market. Our analysis reveals that industry participants (vehicle producers, providers of charging locations, government and policy makers) - with the notable exception of an industry newcomer, Tesla, which has astutely employed platform thinking in its core decisions - have executed a flawed strategy that fails to recognize and leverage the platform aspect of the industry.
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7. Research Agenda
1. Introduction: Are you Playing a Platform Game?

The most successful companies of the last decade have all been platform businesses. Platform businesses create value in unprecedented ways. In April 2020, the five largest stocks in the S&P 500 accounted for 20% of its total market cap, exceeding the 18% concentration level reached during the dot-com bubble. Those stocks are Microsoft, Apple, Amazon, Alphabet (Google), and Facebook. All of them are platform businesses and, with other often cited examples such as Alibaba, AirBnB, Uber and the like, they spearhead what has come to be known as the platform economy.

Looking beyond the headlines, however, chances are quite good that firms are developing platform products even when they don’t recognize them as such. This is because platform thinking extends far beyond the digital platforms and tech giants that everybody is now able to spot. One example is the electric car industry; the various entry approaches of traditional automakers and newer disruptors, such as Tesla, provide the backdrop for our analysis throughout this monograph.

In particular, platform firms increasingly depend upon external actors to provide the necessary complements to create a complete system that delivers value to end users. Another feature of platforms in the way that we discuss them is that the value to a platform’s user is dependent upon the number of other users who also affiliate with the system. This leads to a simplified test to help spot a platform: a product or service value is a combination of an independent product/service value and network value. This means that the utility to a user can be expressed as a function of the standalone value that a user derives from the product or service plus the value that the user gains because other users also join the system. That is, user i’s utility for brand j with quality level \( q_j \) is of the form

\[
V_{ij} = v_j(q_j) + f(N_j)
\]

where \( N_j \) is the network or number of users of brand j . The implication of this network effect is that, unlike traditional goods, a user’s utility is not a constant, and increases as more buyers adopt the good. This creates opportunity for the firm to continue expanding the market as previously low-value users develop higher utility as \( N_j \) grows, as well as to increase its product monetization e.g., through recurring fees or add-on features. But this network effect also creates some distinctive challenges which call for distinctive business strategies which we discuss in Chapters 4 and 5.

Recognizing that a firm is in the platform game is important, as platform markets are fundamentally different from traditional markets, and these differences must lead to distinctive business tactics and strategies. A rule of thumb goes as follows: Platforms exist if a firm is working on a platform product where the value of their product is a function of standalone value and network value consisting of value from same-side (Katz and Shapiro, 1985) and cross-side network effects (Rochet and Tirole, 2003; Parker and Van Alstyne, 2005). Consider, for example, Microsoft’s spreadsheet program, Excel. Excel offers the single user a broad spectrum of functions and features, and delivers great value to users even when they act alone. This value increases even further because users can easily share spreadsheets and collaborate with one another. This collaboration makes it highly unlikely that users who must collaborate would adopt different spreadsheet programs because they would forgo the network component of the value proposition.

Over the last years, a solid theory of multi-sided platforms has been developed and has diffused into management practice, often by using the famous digital platforms mentioned above to explain the mechanisms. By now, many managers won’t have trouble spotting and understanding the mechanisms
at play when a new digital platform emerges. However, the phenomenon extends far beyond digital platforms and chances are good that you are in the midst of developing a platform product, but don't recognize it.

We use the case of electric cars and charging networks to highlight the differences in business strategies between product and platform thinking, and to give a detailed analysis of these to explore the reasons why firms make different choices depending upon the lens they use. Indeed, as we shall demonstrate below, electric cars follow the same platform architectural logic as the widely known examples of digital platforms.

There are three key issues for managers of platform products in the electric car industry. First, managers need to actively work both sides and doing so opens additional strategic options. For example, Tesla actively manages both sides and has the option to switch sides, while traditional car makers who have been passive and have waited for others to solve the problem have given up many strategic options. Second, openness is a critical decision variable. Only when you manage both sides (such as Tesla does) can you afford to have a closed system, otherwise you need to actively pursue an ecosystem strategy. Third, revenue models are not straightforward and can sometimes be counterintuitive. For example, it is almost impossible to develop viable independent business models only for the electric vehicle charger market. The ability to cross-subsidize depends upon participating in more than one part of a multi-sided platform. Firms that operate only on one side of a multi-sided platform are constrained in the business models that they can deploy.

As a case in point, our analysis supports the view that Tesla’s – to many unexplainable – success and lead in the EV segment is on account of pursuing a platform strategy. In fact, Tesla has achieved and maintained this leadership despite substantial weakness on the product front. Journalists and industry analysts alike have often pointed out or even belittled the product performance of the Tesla vehicles: Tesla ranks last on JD Power quality survey with 250 problems per 100 vehicles, for a long time didn’t seem to get basic production right and lived through the infamous production hell, turned to outside body shops to repair scratches and paint defects before cars were delivered to customers. However, from a platform’s good perspective, that is the vehicle and its complementary charging infrastructure, Tesla has the best product and the best options to monetize either side of this multi-sided platform.

This article elaborates on these perspectives by highlighting the platform strategy elements that are relevant in this industry, and then analyzing the crucial factors that have led to the competitive outcomes we observe today.

2. Battery Electric Vehicles as a Platform Good

Moving toward carbon-free societies and economies is a widely proclaimed “grand challenge” of the 21st century (BBC, 2019; White House, 2010; European Union, 2018). One of the most attractive options for addressing this challenge is the mass adoption of Electric Vehicles (EVs). The transportation sector accounted for 28.7% of total carbon dioxide emissions in 2017. EVs present a popular technology to decarbonize this sector with fewer negative consequences than other options for reducing our carbon footprint (Parker, Tan, Kazan 2019), and creating a consensus for action among society, industry, and policymakers. Many politicians and agencies have called for a rapid shift toward EVs from traditional gasoline-powered transportation and have set ambitious goals (UNFCCC, 2015). Increasingly, these
policies and goals are backed by research (Stern, 2007) and evolving public sentiment, with buyers willing to pay premium prices for EVs (Hidrue et al., 2011).

However, the results are sobering. Despite enormous public attention, government support, “car of the year” awards, and high acclaim garnered by some EVs (notably, those produced by an industry newcomer, Tesla), the ambitious goals around EVs have largely been missed. The real adoption of Battery Electronic Vehicles (BEVs) adoption is lagging well behind projections (JPMorgan, 2015). In the U.S., about 17 million automobiles were sold in 2019, of which only about 245,000 were BEVs.²

What has gone wrong? What are the strategies to drive EV adoption and what strategic decisions should players now take? Are there flaws in EV-related policy (e.g., the use and specific design of subsidies (Langbroek et al., 2016))? Or have governments and automobile industry leadership made strategic and tactical errors around the introduction and management of the BEV product?

A cornerstone of our analysis is the observation that a BEV is not merely an “automobile that is electric.” Yet, as we discuss below, the BEV product appears to have been approached by many manufacturers as yet another vehicle that happens to be powered by electricity stored in batteries rather than gasoline stored in a tank. An examination of this strategy begins with a comparison of the introductions of two widely heralded new vehicles during the last 30 years: the Toyota Lexus LS 400 in 1989 as a challenger entrant in the luxury sedan market, and the Audi e-Tron in 2019 as a challenger to Tesla’s present domination of the high-end electric car market.

2.1. Competitive Entry: Challenging a Leader

In 1983, Toyota chairman, Eiji Toyoda, issued a challenge to his company to build the world’s best car (May 2007). At that time, the market for high-end sedans was dominated by storied German brands such as BMW and Mercedes, while the top Japanese brands such as Honda and Toyota were known for making boring reliable and inexpensive cars. Toyota set out to change that with the Lexus LS 400 in 1989. Launched after huge design investments, the LS 400 was heralded by industry experts as a mass-market challenge to existing luxury brand leaders. Reviews hailed its design, build, and performance, with one reviewer³ even calling it “petrifyingly good.” Car-for-car, the LS 400 matched or exceeded the equivalent BMW and Mercedes models.

Toyota’s strategy was a winner. It had no reputation as a maker of luxury cars when Toyota laid out the challenge. Within a decade, Lexus had established itself as a formidable competitor in the luxury market, matching or beating the long-time leaders in brand recognition, market perception, and sales.

Fast forward, thirty years later, to the emerging BEV segment of the automobile market. Although traditional automobile firms have invested in BEV for decades, today’s dominant BEV maker, Tesla itself, was created only a few years ago. Tesla is now the market leader, accounting for almost 80%⁴ of all BEVs sold in the U.S. Today, Tesla vehicles are known for elegant design, pleasing performance (e.g., speedy acceleration and regenerative braking), long range, and an innovative software-driven

¹ https://carsurance.net/blog/tesla-statistics/
³ https://www.motoringresearch.com/car-news/features/lexus-ls-400-review/
approach that makes it a “computer on wheels.” Teslas feature a hi-tech cockpit instrumentation, autonomous driving technology, and customization of interior and exterior performance via software updates. Tesla’s dominance has led to a new breed of challengers.

Traditional auto makers, faced with inevitability of needing to produce vehicles that use renewable energy, have started fighting hard for the BEV segment. Numerous BEV launches were announced in 2019-2020, most prominently the Audi e-Tron all-electric mid-size SUV, and others ranging from the low-end of the market (e.g., Kia Niro) to the top-end with BEV launches from GM (2022 Cadillac Lyrik), Ford (Mustang Mach-E SUV), Jaguar (I-Pace), Porsche (Taycan), Maserati (BEV), Mercedes and newcomers such as Lucid Motors and Rivian.5 Press releases have emphasized the potential for the e-Tron (and other high-end upcoming EVs) to end Tesla’s market dominance. The e-Tron, for instance, boasts that, car for car, it matches vital BEV features exemplified by Tesla S and X models (e.g., flat-floor battery with long range, quick acceleration, powerful touchscreen, etc.) while at the same time bringing the weight of Audi’s brand, reputation, manufacturing capabilities, and historical strength. Industry reviewers were quick and unanimous in heralding the e-Tron as the challenger to Tesla, much like the Lexus’s 1983 entry into the luxury segment.6

What is striking about the Toyota Lexus and BEV examples is the remarkable overlap in the prominent indicators that define the challenger’s attack strategy: a better car, superior engineering, luxurious interiors, fast acceleration, etc. The similarities in the two launches convey the impression that correct business strategy for a new BEV is quite like traditional business strategy for a new gasoline-powered vehicle. That is, make a better car. In the case of the Lexus LS 400, Toyota’s strategy was a big winner. Within a decade, Lexus had established itself as a formidable competitor in the luxury market, matching or beating the long-time leaders in brand recognition, market perception, and sales.

Will any of the widely heralded new BEVs--such as the Audi e-Tron, an outstanding car combined with Audi’s brand, reputation, manufacturing capabilities, and historical strength-- emulate Lexus’s success in the previous era and dislodge Tesla from its complete dominance of the BEV market? Which weapon in Tesla’s armour will be most decisive in fending off the challengers? Will Tesla’s lead in current sales, market share, and brand image help it sustain its leadership position? Or, will Tesla’s dominance in supply of charging stations--dedicated to serving Tesla cars--be the vital strategic defence, making future buyers more inclined to buy a Tesla BEV than an alternative BEV that offers a better car for the money?

Despite similarities in the two launch stories, we posit that the phenomenon and corresponding strategies are not identical. The phrase, “It’s not about the Gizmo,” is an apt summary of the conceptual flaw in the thought process and business strategy around the e-Tron and other BEV launches. The primary reason is that an electric vehicle is not merely an automobile that is powered by an electric battery rather than gasoline.

2.2. A BEV is a Platform Good

We claim that a BEV is more than just an electric vehicle market. It is a platform good. The vehicle itself is only one side of a two-sided market in which the second side is a widespread multi-stall rapid-

charging network for recharging the battery. Rapid-charging so that that the time to recharge is competitive with traditional vehicles. Widespread to assure owners of proximity. And multi-stall to increase chance of availability. Ergo, a BEV product must be managed as a two-sided platform good, with strategically coordinated decisions and investments on both sides of the platform.

We will argue later that the second side, the charging network, is a vital (rather than merely peripheral) aspect of this platform good. We also will argue that this second side has not received suitable strategic attention by BEV makers other than Tesla, and that this is illustrated by the vast gap in investments on the two sides.

To preview the vital role of a two-sided platform strategy, we draw a parallel with proliferation of smartphones and the development of high-speed data networks in the mobile telephone industry. Today’s smartphones are powerful handheld computers, capable of running a plethora of data-intensive applications. The potential to build such powerful handheld computers existed for a few years, however they became a reality and prominent only with the availability of high-speed mobile data networks (Evans et al., 2019). For multiple decades since their invention, cellular telephones were a niche product (with limited penetration up until around 2000) when 2G networks dominated and provided data speeds that were sufficient for little else beyond voice calls and text messaging. It was the diffusion of 3G (and 4G) networks, with data speeds that were suitable for web browsing, email, maps, shopping, transportation, and other data applications, which allowed the development and adoption of the modern smartphone with an ecosystem of third-party apps. As network speeds grew even more (with LTE, 4G, and 5G) smartphones became usable for data-heavy entertainment applications, such as video streaming, gaming, and social media.

To push the analogy further, we note another parallel between wifi networks and BEV charging. While smartphones can draw data from static networks (home, office, hotels, etc.), their adoption and popularity are primarily due to high-speed mobile data networks. If high-speed data were limited to the home or other static locations, a laptop would be better for most needs. Similarly, EVs can be charged either in static settings (home or office) where users spend long hours, or on the road at high-voltage public charging stations. But given the role of the automobile in American life, most potential buyers of EVs would be ill-served in the absence of widespread availability of powerful on-the-go BEV charging facilities.

2.2.1. Then, aren’t gasoline cars network goods too?

Yes, gasoline cars are network goods to the extent that a gasoline car owner gets utility from a network of refueling stations and, conversely, the profitability of a refueling station depends on having a high number of gasoline cars. However, the effect of a gasoline fueling network on the market for gasoline vehicles is starkly distinct from a battery charging network’s influence on BEV sales. There are three crucial, interrelated, reasons: namely, range, network density, and interoperability.

1. Range: The majority of available EVs have a relatively low range (70-220 miles for models such as a Nissan Leaf and 250-350 miles for Tesla models) compared with over 550 miles in comparable gasoline automobiles, such as a Honda Accord (see Figure 1). This range limitation matters because American families routinely drive 300+ mile round-trips for leisure, vacation, and other needs (e.g., a trip from San Francisco to Lake Tahoe), and even longer for inter-city
travel (e.g., San Francisco to Los Angeles). Lack of range would be less consequential if BEV owners had reliable and robust access to a dense network of rapid-charging stations which could recharge BEV batteries as quickly as one fills up a gasoline tank. This is, however, far from reality.

![Driving Range on Full Charge (EVs) or Tank (Honda Accord)](image)

**Figure 1.** Driving Range on Full Charge (EVs) or Tank (Honda Accord).

2. **Network density:** Unlike the widespread network of refueling stations, the network of charging stations is extremely sparse. There are between 1,500 and 3,000 rapid charging stations in the U.S.\(^7\) (defined as capable of supplying 120+ kW power and delivering about 200 miles of range in one hour of charging), including about 1,500 facilities with Tesla’s V2 and V3 superchargers (usually with 10-15 stalls each) and about 200 newer CCS and CHAdeMO DC fast charging stations from EVgo and Electrify America\(^8\) (of which several have only a handful of stalls). This number pales in comparison to over 168,000 public fueling stations for gasoline vehicles.\(^9\)

3. **Interoperability:** Even the relatively small number of BEV rapid charging stations is further fragmented due to lack of interoperability caused by multiple technical specifications and non-cooperative ownership and access across systems. In particular, Tesla alone has over 1,500 supercharging locations in the U.S., accessible only to Tesla models. In contrast, owners of other EVs have access to only a few hundred stations (presently with lower performance) operated by Electrify America and EVgo.

To summarize, at this point in the BEV product cycle, the decisions of whether to buy an EV, which one, and how and where to use it, are dependent heavily on the availability and nature of the charging network (Gnann et al., 2018; Egbue and Long, 2012; Haddadian, Khodayar and Shahidehpour, 2015;\(^7\) The wide range 1,500-3,000 is quoted because some number of CCS and CHAdeMO chargers operate at 50 kW (not rapid-charging). Based on [https://afdc.energy.gov/fuels/electricity_locations.html#findnearest?fuel=ELEC](https://afdc.energy.gov/fuels/electricity_locations.html#findnearest?fuel=ELEC). Also [https://www.theverge.com/2018/10/3/17933134/ev-charging-station-network-infrastructure-tesla](https://www.theverge.com/2018/10/3/17933134/ev-charging-station-network-infrastructure-tesla). There are about 10 times as many Level 2 chargers operating at around 50 kW, however these deliver only about 50 miles range per hour, hence are not suitable for long distance or inter-city travel.\(^8\) As of June 2019, according to [https://www.techspot.com/news/80410-electrify-america-has-deployed-ev-charging-stations-across.html](https://www.techspot.com/news/80410-electrify-america-has-deployed-ev-charging-stations-across.html).\(^9\) [https://www.fueleconomy.gov/](https://www.fueleconomy.gov/)
Linke, 2017), and that this decision process is starkly different from that for buying a traditional gasoline vehicle.

2.2.2. Do auto makers’ BEV strategies reflect BEV as a platform?

The traditional business strategies developed and honed for the gasoline vehicle market are insufficient for BEVs because of the platform effects in the BEV market. A recent article in Forbes vividly lays out the charging dilemma faced by BEV owners today. Given the specifications and trade-offs inherent in rapid charging technology (Scrosati et al., 2015) and the density of such facilities, BEV owners often must either depend primarily on slow charging at home or typically drive 20-50 miles to reach a rapid-charging facility, and then spend an hour for re-charging the battery, unlike owners of gasoline automobiles, most of whom can quickly reach a station and fill a tank within 5 minutes. Moreover, while owners of gasoline vehicles face a favorable supply-demand gap of refueling stations leading to quick search and discovery and minimal wait times, the shortfall in supply of BEV charging facilities is highlighted in reports by the International Council on Clean Transportation (Nicholas, 2019) and the Center for American Progress11 indicating that closing the present supply-demand gap will require an investment of over $2.2 billion.

In contrast to this interpretation of a BEV as a two-sided platform good, we believe that, with the notable exception of the newcomer Tesla, platform thinking has not been widely adopted in business actions in the BEV industry. These firms are reported to collectively invest over $200 billion in building BEVs but barely over $2 billion on laying out a rapid charging network. Only Tesla both builds cars and operates a network of supercharging stations spread throughout the country. These stations (analogous to gasoline stations) provide Tesla vehicles the ability to replenish batteries with approximately 200 miles of driving range in an hour of charging. Depending on timing and conditions of purchase, Tesla owners pay either zero or low fees for using this network of stations. Other BEV makers, however, have not actively built or invested heavily in a first-party charging network.

The similarities between launches of Lexus LS 400 and Audi e-Tron provide another clue that industry has largely viewed BEV strategy as “make a better vehicle with a bigger battery.” While Tesla spent ten years investing in a supercharging network and, consequently, sacrificing operating profits from building and selling EVs, other auto makers invested billions of dollars in building fancy vehicles but have failed to take deliberate action towards creating a charging infrastructure. As a result, Tesla’s dominance on the second side of the platform good—a proprietary supercharging network that is far greater than that of all of its competitors combined—endows it with enormous advantage in competing for future BEV buyers.

Like automobile manufacturers, the lack of platform thinking also is apparent in policy making for EVs. Success of EVs requires that a robust rapid-charging network be developed and nurtured in a very deliberate and strategic way. The absence of coordination between auto makers—who are, in fact, competitors in the traditional market—underscores the role of policy in driving the growth of this new technology. Instead, policy makers in the U.S. have relied largely on the market to provide the supercharging network, focusing instead on providing subsidies for either BEV development or BEV purchase. Only recently there have been some efforts to coordinate actions and investments. For

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11 https://www.americanprogress.org/issues/green/reports/2018/07/30/454084/
instance, Volkswagen was driven to invest $2 billion into a new subsidiary, Electrify America, toward building a network of charging stations, as part remedy for its emissions scandal;\textsuperscript{12} similarly, Ford and Volkswagen recently announced a partnership with Amazon to build a supercharging network.\textsuperscript{13}

2.3. The Charging Station Dilemma

Based on our anecdotal observations, many people are unaware that charging a BEV at these supercharging stations takes about one hour, or that Tesla’s supercharging stations are unavailable to non-Tesla EVs. In general, potential buyers of EVs are frustrated both by the limited availability of charging stations and the lack of interoperability across stations and vehicles.

Why are there so few rapid-charging facilities, and why are they further fragmented between non-compatible systems? The reason is that most BEV makers, except Tesla, have not implemented a business strategy based on a two-sided platform perspective. Thus, development of charging stations is left to independent third-party firms who face an investment dilemma. They have little incentive to build a dense network in the absence of a large installed base of users; the latter, of course, is thwarted by the absence of a dense network of charging facilities. Lack of coordination with BEV makers makes developers of charging facilities less willing to take a leap of faith and build out the network based only on hope that BEV buyers will follow. Tesla solves this coordination problem by building both EVs and chargers. Consequently, having invested heavily in building rapid-charging stations even at the expense of operating profits, Tesla has no incentive to share its facilities with competing BEV makers. Meanwhile, among the non-Tesla charging facilities that are developed by third-party firms, occasionally in some kind of loose alliance with a subset of BEV makers, the further division follows the usual script in two-sided platforms where different solutions are initially incompatible either due to engineering or business considerations. Therefore, while people are used to refueling their gasoline at any petrol pump, the same does not hold for their EV. In some cases, plugging ports are incompatible. In others, a user must first become a “member” before being able to access a charging port. This, in turn, drives the adoption dilemma for potential BEV buyers.

2.4. The Buyer’s Dilemma: Gasoline or Electric Vehicles

Consider a representative consumer’s demand and adoption of a gasoline automobile vs. a BEV. Suppose there is a set $1 \ldots J$ of gasoline vehicles and a corresponding set $0, 1, \ldots J$ of BEVs, with Tesla (as a BEV-only player) representing brand 0. For both gasoline vehicles and BEVs, a potential buyer gets utility from purchasing the vehicle and from driving it, with the latter creating a need for refueling or recharging. As in Chapter 1, let us think of the representative consumer's utility for brand $j$ as comprising a standalone value plus a network benefit, the latter being a function of the network of refueling or charging stations available to users of that brand, and possibly an expectation regarding upcoming stations.

Consider the case of electric vehicles first. Writing $n_{jt}$ to denote the number of brand-$j$-compatible charging stations installed during time period $t$, and assuming no attrition in stations, the number of stations available at time $t$ is $N_{jt} = \int_t n_j d_t$. For Tesla ($j=0$), this implies that for a buyer looking to purchase at time $t$, utility is

\footnotesize
\begin{itemize}
  \item [12] \url{https://www.autonews.com/article/20181028/OEM06/181029805/vw-s-charge-electrify-america}
\end{itemize}

12

13
\[ U_{0t} = v(q_0) + f(N_{0t}, E[N_{0t}]) \]

Where \( E[N_{0t}] \) represents an expectation regarding upcoming stations after time \( t \). Limiting our attention to Level 4-5 rapid-charging stations, it is notable that \( E[N_{1t}] \) is about 15,000 (1,500 stations times about 10 stalls per station), that Tesla is quite forthcoming and transparent about plans for additional stations (i.e., users can form their expectations \( E[N_{0t}] \) and further that Tesla has been successful in fulfilling expectations in recent years. Crucially, Tesla-compatible stations are predominantly developed and owned by Tesla itself. In addition, as we see below, a small number of non-Tesla stations are also available to Tesla users, then enhancing the utility function beyond what is stated above.

The picture for non-Tesla BEVs \((j \geq 1)\) is rather different. First, charging stations are not predominantly supplied by the OEM BEV-makers. Second, there are multiple technologies and payment models involved, creating some lack of interoperability across stations and brands. If we were to relax this concern and assume full interoperability, then the total number of stations available to brand \( j \) at time is simply \( N_t \) (i.e., we can drop the index \( j \), and aggregate the supply of stations for all \( j \geq 1 \) brands). Even with this relaxation, \( N_t \) is substantially lower than \( N_{0t} \). Moreover, given the myriad firms involved in developing charging stations, and lack of economic and technological coordination between station providers and BEV makers -- and also lack of transparency and a track record of success in fulfilling promises -- consumers are unable to assign high values to \( E[N_t] \). Therefore, comparing the utility functions for Tesla vs non-Tesla BEVs, it becomes clear that even a high-quality BEV will face a competitive disadvantage against Tesla because of the additional utility created by \( N_{0t} \) (and \( E[N_{0t}] \)) vs \( N_t \) (and \( E[N_t] \)). This perspective also makes it clear that a well-developed and executed strategy regarding charging stations is a vital element of competitive strategy in the BEV market.

Now, consider how a buyer’s decision model plays out for gasoline vehicles. Following similar notation, let \( M_{jt} \) and \( E[M_{jt}] \) represent cumulative number of refuelling stations available to brand \( j \) users at time \( t \). In this case, however, it is well-known that there is nearly perfect interoperability across charging stations and brands. Thus, we can again drop the subscript \( j \), aggregate the supply of refuelling stations, and simply denote the available number as \( M_t \) and future expectation as \( E[M_t] \). A representative buyer’s utility for brand \( j \) then is of the form

\[ W_{jt} = v(q_j) + g(M_t, E[M_t]) \]

Here it is notable that \( M_t \) is about 160,000 and thus much greater than \( N_{0t} \) or \( N_t \). This implies a) a comparative disadvantage for BEVs over gasoline vehicles, and b) that \( E[M_t] \) is less relevant to the decision process due to the high value for \( M_t \), and because users are confident that the huge installed base of gasoline vehicles will ensure a future build-up of refuelling stations. More crucially, we note that for a buyer who is comparing multiple gasoline vehicle brands \( j_1 \) and \( j_2 \), the network of refuelling stations is irrelevant to that comparison! Therefore, competitive strategy within the segment of gasoline vehicles can ignore the second side of the market (refuelling stations) and entirely focus on the first side, the vehicle itself. Thus, competitive strategy for BEVs is quite different from that for gasoline vehicles even though in both cases one could frame the utility as a combination of standalone product value and a network benefit.
Indeed, this discussion is reminiscent of the advent of gasoline vehicles when cars began to displace horse-driven carriages and when Ford introduced Model T as a mass product. Although there were few gasoline stations in the early years of gasoline cars, customers could arrange for refuelling by picking up gasoline cans at a pharmacy or blacksmith shop. There is no analogous service for batteries for BEVs, making the role of charging stations more severe and decisive.

2.5. Needed: A Platform-Aware Strategy and Policy for BEVs

The understanding that BEVs are not a “product,” i.e., a car that is electric, but rather one side of a two-sided market enables a change in perspectives. The action space that is available to decision makers of all kinds increases significantly. A substantial economic and business research stream on two-sided market platforms has developed a robust theory of how these markets are fundamentally different, and how these differences must lead to distinctive business tactics and strategies. Recognizing that a business or product follows the laws of two-sided markets is a necessary condition, but not sufficient. Additional impediments exist, ranging from general organizational inertia, a lack of necessary skills and personnel, and the innovator's dilemma. On one side, since the beginning, electric cars have been a threat to the profitability of conventional gas-powered automakers, hence the business logic prevents investments. Further, a product-focused organization perfects the product; a platform organization perfects the platform. “The cost of developing the Tesla Roadster and Model S were around $140 million and $650 million whereas General Motors spent $1 billion developing its first electric, the EV1, and $1.2 billion developing the Chevy Volt, and Nissan has spent $5.6 billion developing its relatively low-performance electric cars” (Stringham, Miller & Clark, 2015, p.91), while Tesla split its investments on both sides of the market and in parallel developed the charging infrastructure. Moreover, more challenges exist that are specific to products with a multi-sided market architecture.

The lone exception to the lack of platform thinking in designing business strategy for BEVs is Tesla, the new entrant into the automobile market. From its earliest years, Tesla has made strategic choices that align with the distinctive challenges of operating in a two-sided market. A key manifestation of this is Tesla’s decision not only to invest heavily in making great cars, but also to make massive investments in building a wide and powerful supercharging network. The result is that even though several established automotive OEMs, such as Nissan, BMW, and Chevrolet, invested early and heavily in R&D and new engineering platforms for BEVs, and developed new designs to position themselves as the frontrunner in the race for future mobility, Tesla emerged as the most successful and celebrated electric car manufacturer despite being a newcomer operating in an old Toyota/GM plant. Today Tesla accounts for between 75% and 85% of the BEVs sold in the U.S. Tesla’s supercharging network not only is the most dominant and widespread, Tesla also chose to make it a closed proprietary system (which gives Tesla a huge advantage when competing for new customers) and to subsidize its usage by having a joint coordinated price for the car and access to the network. Moreover, Tesla has built an integrated information structure which provides real-time visual information regarding location and availability of charging stations, and its route planning software factors in knowledge of charging locations in space and their availability in time. All of these factors reflect a platform-aware perspective that is missing.

https://aoghs.org/transportation/first-gas-pump-and-service-stations/
from makers of competing BEVs. Indeed, Tesla has gone well beyond a basic platform strategy by also investing in the idea of battery electric cars as a vital component for future decentralized renewable energy systems.

2.6. Organization and Summary

The rest of this paper reviews relevant platform theory and then applies it to the BEV industry to illustrate and explain successes and mistakes by the players. We critically examine important past decisions and events, and then provide guideposts for the future evolution of the industry. For instance, this discussion provides insights into the likelihood of interoperability between charging stations. It also provides a framework to examine Tesla’s incentives to continue operating on both sides of a closed two-sided platform, versus licensing the charging infrastructure to competing carmakers. By telling this story, we introduce the importance of platform literature to the operations management community and conclude with fruitful research opportunities that lie at the intersection.
3. BEV Industry to Date: Decisions and Challenges

This section lays the necessary foundation to later examine the strategic decisions taken by actors in the BEV industry, such as established automakers and new challengers, charging site operators, and municipalities, governments and industry associations.

3.1. Toward Sustainable Mobility with Electric Driving (1830 - 2000)

It may appear that electric vehicles are a new phenomenon enabled by new technologies (such as the lithium-ion battery technology). On the contrary, electric vehicles date back to experimental products that were already on the scene by the 1830s as their development was closely linked with the invention of (lead-acid) batteries (McFadden, 2018). Indeed, the electric vehicle transportation system was directly competing with other modes of transportation, such as gasoline and steam, at the end of the 19th century to become the dominant automotive technology (Kirsch, 2000). For a brief period, the electric vehicle even appeared to be getting ahead. At the end of the 1890s, the Electric Vehicle Company (EVC) was the largest vehicle manufacturer in the United States (Kirsch, 2000). The company offered a range of different transportation services that are familiar today: private ownership, unlimited recharging for $5 per month, and “electric hansom cab service, omnibus service for a select number of hotels, and limited public transport service” (Kirsch, 2000, p.67).

In many ways, history seems to repeat. The 19th century BEV industry faced similar challenges as the ones faced by today’s Bev firms. Already in the 19th century, the Electric Vehicle Association of America tried to standardize the eight existing plugs to one standard, battery voltages to standardize controllers, motors and other subsystems (Kirsch, 2000), as well as the mutual complaint by central station owners (today’s charging stations) and car manufacturers that their respective business practices prevent the expansion of the electric vehicle market (Kirsch, 2000). At the same time, the success of the technology was interdependent on other actors’ decisions, such as the expansion of the electrical grid to enable out-of-city transportation. In the end, the success of gasoline cars over electric vehicles cannot be explained only by a direct technology-to-technology comparison, but by a comparison of choices of transportation system to transportation system (Kirsch, 2000).

Following this period, the internal combustion engine became dominant for over a century, but EVs re-emerged as a concept in the 1960s and 1970s with soaring oil prices and gasoline shortages (Matulka, 2014; Kirsch, 2000), and prototypes produced by big car manufacturers (e.g., GM converted an Opel Kadett using a zinc-air battery with a claimed range of more than 200 km). However, real attention started at the end of the 1980s and the beginning of the 1990s because of increased attention to air pollution and concern over the predicted end of the fossil fuel era (e.g., “Peak Oil”). In 1990, California introduced its first zero-emission regulations, which were instrumental in sparking new initiatives in developing electric vehicles during the 1990s.

With the introduction of Toyota’s Prius and Honda’s Insight and their impressive sales numbers, the industry demonstrated that electrification in transport is not a matter of backyard production. Both models are hybrid electric cars, where the electric systems (the batteries and the electric motor) still fulfill crucial functions, but only in combination with an internal combustion engine, either driven by gasoline (petrol) or diesel fuel (Hoyer, 2008). Since then, a multitude of new hybrid electric vehicles have been introduced. The possible combinations of internal combustion engines with some form of
electric systems are almost endless. However, lately the so-called plug-in hybrids gained significant market traction because they are not so dependent upon an extensive electric recharging network but, instead, can depend upon the existing fossil fuel infrastructure.

The pressure to fully decarbonize individual transport has continued and appears to be gaining momentum (Hertzke et al., 2019). As a result, fully battery electric vehicles have been introduced and an accompanying charging network was established. The current success in network growth is largely because of Tesla’s efforts to produce desirable battery electric cars. The following sections give an overview of the timeline of BEVs.

### 3.2. Early Experimentation (2000 - 2010)

In 2003, Tesla Motors started with the development of its first fully electric car, the Tesla Roadster. The Roadster, which is based on the Lotus Elise, was introduced in 2008, promised a range of 200 miles per charge, and was sold for $98,950. The model sold approximately 2,500 units (limited through a pre-agreed sourcing contract with Lotus) and Tesla stopped production in 2012 (Woody, 2012).


Also in 2009, Nissan unveiled its new electric car, called the LEAF ("Leading, Environmentally Friendly, Affordable, Family Car"). The LEAF is capable of a maximum speed of more than 90 mph, can travel 100 miles on a full charge, and has a battery that can be recharged to 80% of its capacity in 30 minutes. Nissan planned to work with the Japanese government and private companies to set up charging station networks across several countries (Squatriglia, 2009). With its range and size, the LEAF design concept could cover 80% of the trips of a typical commuter, only leaving out long distance travel (Neil, 2010). In 2010, Nissan priced the LEAF at roundabout $32,000 in the U.S. and started to take reservations (Linebaugh, 2010; Ramsey, 2010).

Additionally, with the introduction of low-range and ultra-small vehicles, e.g., Mitsubishi i-MiEV, Peugeot iON, and Citroen C-Zero, the range of BEV products available to the customer increased substantially. All of these latter cars are similarly constructed and offer about 62 miles (100 km) of driving range per full charge, and had an initial selling price in the U.S. of $27,990. They were clearly aimed at an urban population with a short commute.

Also in 2009, Tesla presented the first prototype of the Tesla S, a sedan which was heralded as being practical and sexy, and pressed Tesla head to head with the likes of BMW, Mercedes, Audi, and Jaguar (Squatriglia, 2009a).

During the 2000-2010 timeframe, new concepts and technology standards for charging were developed. In 2007, Better Place, which focused on battery swapping, was founded. In 2009, the charging standard type 1 (SAE J1772) was completely overhauled, and the charging standard type 2 was developed in
Germany (Mennekes, 2012). Nonetheless, there were considerable challenges surrounding battery technology, peak charging rates, longevity, and the development of charging standards. There also were questions about the appropriate markets for electric vehicles and how long they could occupy a premium price point in the market. As the technologies matured, there were signs that wider adoption might be possible.


Starting in 2010, three new models became available to customers in various markets: 1) the sub-compact Renault Z.E. (Zero Emission) Zoe (depending on the model, 200-240 km range, available fast charging, and over 90,000 models sold to date), 2) the sedan Chevrolet Volt, and 3) the Nissan LEAF in serial production. Three industrial entities, Schneider Electric, Legrand, and Scame, announced the formation of the “EV Plug Alliance” “to promote the use of a high safety plug and socket solution for Electric Vehicle charging infrastructure” (Legrand, 2010).

In 2011, the standard specifications for the CCS (Combined Charging Standard, a combination of AC and DC charging) were published (BMW, 2011; Daimler, 2011). The standard was co-developed by Audi, BMW, Porsche, Volkswagen, Ford, and General Motors, which promoted its use as the new de facto standard (BMW, 2011; Daimler, 2011). Further, in March 2011, the number of charger manufacturers that developed and offered the initially Japan-based CHAdeMO DC quick charging standard increased from 5 to over 20 worldwide (Chademo, 2019). As a result, the number of installed chargers reached 582 in Japan and 41 in other countries. In 2011, BMW launched the sub-brand, BMWi, under which it made plans to market its future line of electric cars. It announced two models: The i3, a four-seat city car expected to be priced at a slight premium from $30,000 to $40,000, and a higher-end plug-in hybrid sports car called the i8 (Fuhrmanns, 2011). Nissan reported monthly sales of the LEAF of more than 4,000 in June and raised the price of the car by about 7% (Ramsey, 2011). Nissan sold almost 10,000 LEAFs in 2011 (Terlep, 2012).

Reports claimed that the charging infrastructure was quickly increasing because of many companies investing, but the cars were still lacking (Hagerty & Ramsey, 2011). At the same time, OEMs continued to claim the lack of charging infrastructure as a challenge to BEV adoption (Murphy, 2014). This illustrates the challenges and a paradox of EVs as multi-sided platforms: If you would ask either side of the markets (OEMs or operators of charging infrastructure), they would simultaneously claim that there are not enough participants on the other side of the market (see chapters 2.5 and 5.1). OEMs see a lack of charging infrastructure for customers to widely adopt BEVs, and charging site operators report the lack of cars as an impediment to a viable charging infrastructure and greater investment.

In January 2012, the CHAdeMO protocol version 1.0 was published. From March 2010 to March 2012, member companies grew in number from 158 to 429 with the international regular member segment showing the highest growth rate, confirming the global appeal of the CHAdeMO protocol (Chademo, 2019). Also in March 2012, German and U.S. carmakers declared the CCS as their de facto future standard (General Motors, 2012). In June 2012, Tesla delivered the first Tesla Model S to its customers (Boudreau, 2012). The Tesla Model S addressed the luxury care segment with its specifications (rapid acceleration, large-scale touch panel, range of over 300 miles), and list prices (after a $7,500 Federal tax credit) of $97,900 for the "Signature Performance" model (Hirsch, 2012; White, 2012). Also in 2012, Tesla announced the Tesla Model X (Bloomberg, 2019; Garrett, 2012).
In 2013, BMW joined the mass market electric vehicle club (White, 2013). BMW launched the i3, which was positioned in the same segment as the mid-segment BMW series 3. It offers roughly a range of 200 km and the possibility of quick charging. The design of the model clearly departed from BMW design standards which makes the car easily recognizable as BMW’s electric car. Also in 2013, Tesla established its first superchargers on the U.S. West and East coasts (see Figure 2 and offered free charging to its customers (Hirsch, 2012). Further, Tesla announced that it would offer battery swap stations (Green, 2013).

Meanwhile, the competing fast charging standard CHAdeMO offered nearly 900 fast charging units in Europe and more than 300 units in the U.S. (Chademo, 2016; see Figure 3.

In the meantime, product rollout delays were a regular occurrence and Tesla pushed back the release of the Model X crossover SUV by one year to late 2014 (White, 2013). After the excitement and the launch of new models in the previous years, in 2013, some disillusioned observers questioned the euphoria amid disappointing car sales (Lane, 2013).

Figure 2: Tesla supercharger U.S. locations in 2013. (Source: Tesla/Twitter)

Figure 3: CHAdeMO’s available fast charging network in 2013 (Chademo, 2013).
In 2014, the charging network for the different charging standards was advanced. Tesla was able to open a coast-to-coast supercharger connection in January 2014 (Figure 4); they filed a patent for allowing a charging station to prioritize charging based on need and arrival time and, by the end of 2014, the firm offered 884 individual charging points spread across 141 supercharger stations in the U.S. (see Figure 5). Comparably, CHAdeMO increased its charging network to 776 charging stations in 2014. Tesla signaled their ambition to significantly extend the charging network in 2015 (see Figure 6). Tesla also announced its third model (Model 3) with a plan to go on sale in 2017 for about $40,000 (Hirsch, 2014).

Additionally, in 2014, the European Union defined the CCS charging standard as the standard for fast charging in the European Union and released specifications for public charging infrastructure (EU,
Also in 2014, Tesla offered open licenses to its patents to any company that wanted to build electric vehicles and suggested that BMW was already interested in sharing patents (Ramsey, 2014). Further, Tesla communicated that it would install the first battery swap station in 2015 (Stoll, 2014). Nissan pushed back its plans to sell a combined 1.5 million BEVs worldwide by four years to 2020 amid consumer complaints about a shorter range than combustion-engine cars, lack of recharging infrastructure, and comparatively high prices (Nam, 2014).

In January 2015, Elon Musk, Tesla’s CEO, signaled that the Model 3 could sell for approximately $30,000 (Woodyard, 2015). Tesla launched its new SUV Model X at a base price of about $81,000 (Ramsey, 2015; Ramsey, 2015b). Tesla also further expanded its supercharger network to almost 500 locations in the U.S. by the end of 2015 and 200 locations in Europe; Tesla was opening a new supercharger location almost every day. CHAdeMO released a new protocol for its charging standard (the version 1.1) and offered about 10,000 charging locations across the globe, with a strong focus on Asia. Tesla announced the Model 3 to be unveiled in 2016 (Bloomberg, 2020) and claimed a new starting price of $35,000 (Randall, 2018). BMW and Volkswagen jointly agreed to work with ChargePoint to invest $2 million to install 100 chargers along the East and West Coasts of the U.S. (VW sold 357 of its e-Golf model and BMW roughly 6,000 EVs in 2014 in the U.S.) (Bennett & Ramsey, 2015).

Customer complaints arose because superchargers often were crowded by local users instead of their intended use of making long-distance travel possible, leading to long waiting times (Ramsey & Proper, 2015). Figure 7 shows the locations of Level 3 charging stations in the U.S. as of September 2015.

Chevrolet unveiled the Bolt, an all-electric car to be available in 2017 with a range of 200 miles and an estimated price of $30,000 (Neil, 2015).

In 2016, Tesla introduced a fleet-wide idle fee that aimed to increase supercharger availability and announced that the end of free charging would be coming (and, in fact, already applies to the new Model 3 (Ramsey, 2015). Early in 2016, Tesla began to take reservations for the Model 3, which would be ready in late 2017 (Bomey, 2016); Tesla received 373,000 deposits of $1,000 each in the first weeks (Bloomberg, 2019).
Elon Musk, CEO of Tesla, laid out a “Master Plan.” Highlights included an electric cargo truck, a new-style electric bus, a smaller set of vehicles than current models, autonomous features making vehicles capable of operating without a human driver, a pickup truck, a small SUV, and an all-in-one renewable energy package to combine rooftop solar power with a Tesla battery pack (Mitchell, 2016).

In 2017, Tesla launched the Model 3 as a mid-class model to customers (Bloomberg, 2019). Also in 2017, Tesla added a live availability feature for its charging stalls, changed the charging model from “free” to “free for the first 400 kW per year,” and extended the charging network to more than 10,000 superchargers and 15,000 destination charging connectors around the world (Higgins, 2017). By the end of 2017, IONITY, a consortium created by BMW, Daimler, Ford, VW, Audi, and Porsche, announced plans to build 400 CCS fast charging stations along European highways with subsidies from the European Union of €39 million. Tesla announced that it would triple the size of its supercharger network between mid-2017 and the end of 2018 (Bloomberg, 2019) and introduced the Model Y for 2019 (Bloomberg, 2019). It is worthwhile for the later analysis to note that Tesla's announcements included both cars and chargers, while the charging aspect is mostly absent in the announcements of other carmakers.

Daimler became the lead investor (with $82 million) in ChargePoint and their European expansion plans (Boston, 2017).

Pan-European electricity utility, E.ON, announced plans to install 10,000 individual charging points over the next several years in Europe (Mitchell, 2017).

Tesla announced that the new SUV Model Y would be on the roads in 2019 and expected that the demand would probably exceed the demand for the Model 3 (Higgins, 2017b).

The Volkswagen-funded Electrify America planned to spend $2 billion over the next 10 years to build charging infrastructure (Roberts, 2017).

Nissan introduced a new version of the Nissan LEAF with an increased range of 151 miles per charge and an entry price of under $30,000 (McLain, 2017; Neil, 2018); and the Chevrolet Bolt with a range of 238 miles became available for a price under $30,000 (Neil, 2017).

In 2018, another consortium, called MEGA-E, received subsidies (€29 million) from the European Union to establish fast charging stations as charging hubs where all different kinds of electric vehicles (including Tesla) could charge. In August 2018, Tesla claimed that 99% of the U.S. population lives within 150 miles of a supercharger. Tesla and EVgo have the largest shares of fast charging stations in the U.S. (see Figure 8), while in other parts of the world the operators of charging networks differ (see Figure 9).

Volkswagen announced plans to build at least 16 electric-vehicle plants by 2025, of which nine would be in operation by 2020 (Boston & Bernhard, 2018).

ChargePoint announced plans to develop 2.5 million BEV "charging spots" (it is unclear on which charging speed level) by 2025, up from its current 54,000, in response to the growth in BEV adoption (Walton, 2018).
EVgo and Tesla have the largest share of fast charging stations in the U.S.

![Ownership of fast charging stations in the U.S., 2018](image1)

Figure 8. Ownership of fast charging stations in the U.S., 2018

![Breakdown of charging points by operator type and country/region.](image2)

Figure 9. Breakdown of charging points by operator type and country/region.

### 3.4. Challenges

The industry faced a number of challenges during the past two decades, organized into two sets. The first set includes four challenges related to product market fit and how to guide product development and customer education efforts. Central among these is the key design trade-off of price versus range. Most firms opted to keep product price fixed to a target range and then maximize range during their product development effort, subject to an overall budget constraint. The second major challenge that the industry faced was how to find suitable partners who could offer a charging infrastructure. This second challenge was directly related to quelling the third challenge called range anxiety, the term coined to refer to potential customers’ worries about running out of power before completing their trips. A fourth challenge the industry faced was the need to better explain the total cost of ownership (TCO) for battery electric vehicles (BEV) relative to their petroleum-fueled counterparts. The economics for BEVs improves over time because of their higher efficiency and lower operating costs, but this logic appealed mostly to more affluent customers who could afford to take the long view.

The second set comprises three additional challenges that were more operational in nature. First, the industry in general, and Tesla in particular, faced significant problems with production ramp up. This created marketing issues because of repeated delays in getting product to market in sufficient quantity to satisfy demand. A related supply chain issue was the challenge of installing sufficient charging infrastructure to make BEVs a viable choice for long distance travel. Finally, firms faced a large set of choices with respect to how to accomplish the goal of creating a recharging network. These choices
included which standards to promote, which consortia to join, and how to guide the development of the regulatory framework to operate under.

Going forward, it is clear that the industry is beginning to achieve critical mass as incumbent manufacturers announce ambitious new product plans.

3.5. New Generations and Consumer Choice (2020 and Beyond)

In 2019, the Tesla Model 3 became available in the market and at launch only a $49,000 premium version was able to be ordered (Bloomberg, 2019). Additionally, in 2019, a wide range of traditional OEMs announced plans to offer a new generation of BEVs, with car specifications comparable to Tesla’s offering. Overall announced pipeline of new BEV models began to grow substantially. Some highlights are listed below:

- **Volkswagen** communicated a “Roadmap E” strategy to launch 50 new electric models by 2025 with the most affordable version being less than €20,000 (Manthey, 2018).
- **Audi** promised to offer three new models by 2020 (Collie, 2018).
- **BMW** wanted to have 25 electrified models on sale by 2025, with 12 of those to be pure-electric (Collie, 2018).
- **General Motors** committed to offer 20 electric vehicles by 2023 (Collie, 2018).
- **Volvo** said it will have an electrified powertrain in every vehicle released from 2019 onwards; with five fully electric vehicles to hit the market between 2019 and 2021 (Collie, 2018).
- **Mercedes-Benz** expected 10 full-electric models in showrooms by 2022 (Collie, 2018).
- **Ford** projected 13 electrified models to arrive by 2021 (Collie, 2018).
- **Tesla** announced the Model Y as a mass-market SUV (built on the Tesla 3 foundation) to be launched in 2020 (Isidore, 2019).

With respect to the charging infrastructure side, highlights\(^\text{15}\) include Tesla’s plans for further expansion of its U.S. network (see Figure 10). The demand for fast charging ports is estimated to grow to approximately 100,000 by 2030 (Cooper & Schefter, 2018). Additionally, there is already secured funding of about $3.4 billion for expanding the fast charging network in the U.S. (Cooper & Schefter, 2018).

\[^{15}\text{We do not claim to provide an exhaustive list of vehicle or charger announcements, rather we want to give a feeling for the context.}\]
● The European Automobile Manufacturers Association’s ask for setting mandatory targets for charging points and refueling stations (ACEA, 2020) linked to the EU Green Deal\textsuperscript{16} and EU recovery plan.

● The America’s Transportation Infrastructure Act of 2019 (ATIA) includes a $1 billion funding program to build hydrogen, natural gas and BEV fueling infrastructure (see Figure 11).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure10.png}
\caption{Tesla’s supercharger expansion plans (Source: Tesla/Cleantechnica, 2019).}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure11.png}
\caption{Planned investments in BEV charging infrastructure (Cooper & Schefter, 2018).}
\end{figure}

3.6. General Economics and Operational Aspects of BEVs

3.6.1. Complementarities: Range, battery size, charging stations

The deployment of fast/rapid/ultra-fast charging networks and the development of longer vehicle ranges can be regarded as either complementary or substitutes. Both directly affect the daily distances possible with a BEV. However, the effect of longer battery ranges on the demand for fast-charging infrastructure is not straightforward. On the one hand, long-range BEV may reduce the need for public charging since home charging might be sufficient for most trips, even longer ones. On the other hand, long-range BEV

could be used more and more for long-distance trips, thus increasing the demand for public fast-charging infrastructure (Funke, Plötz and Wietschel, 2019).

Additionally, this poses a critical challenge common to most platform architecture products in that decisions are interdependent and need to be coordinated across two or multiple sides. The decision of a car manufacturer to increase the range of its future models should generally be accompanied by investments in more fast charging infrastructure, or vice versa. In this, the management of platform products differs substantially to classical pipeline products.

3.6.2. Costs of the complement

It also is critical to understand the importance of the complement for the diffusion as well as to get an overview of the economics to understand industry actors’ decisions. BEVs need a public fast charging infrastructure to fully compete against gasoline cars. Charging infrastructure is subdivided into different levels of charging speeds. Levels 1 and 2 use alternating current (AC) and have capacities of up to 22 kW. The application of these levels of charging are mostly for at-home and destination charging. Levels 3, 4, and 5 use direct current and are widely known as fast charging (or also referred to as a Direct Current Fast Charger (DCFC)). However, there exist significant differences within this category of fast charging and it likely will evolve considerably in the future. For the purpose of this paper we follow Lee and Clark (2018) and define the variances in fast charging as follows:

- Level 3: delivery of ~50 kW (fast)
- Level 4: deliver of ~150 kW (rapid)
- Level 5: delivery of ~350 kW (ultra-fast)

Most third party DCFCs are operating at about 50 kW, while Tesla’s superchargers typically operate at ~120 kW and correspond most closely with Level 4 (Lee & Clark, 2018).

The cost of building fast charging infrastructure is dependent on many different factors, such as hardware costs, permissions, complexity of utility interconnection processes, location, local regulations, etc. In general, these costs are poorly understood, very difficult to quantify, and rarely documented in the literature. Two teams of researchers documented the costs to build Level 3 and above charging infrastructure. Funke et al. (2019) estimated the costs for fast charging stations as a function of their size (see Table 1) Lee and Clark (2018) estimated the capital costs per charger for the U.S. (see Table 2).

<table>
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<th>Number of charging points per station</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<td>€227,000</td>
<td>€255,500</td>
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<td>€117,000</td>
<td>€185,500</td>
<td>€229,000</td>
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</tbody>
</table>
Table 1: Estimated costs for fast charging stations as a function of size (base year 2017) [w/o VAT] (Funke et al., 2019).

<table>
<thead>
<tr>
<th>Capital Costs</th>
<th>Residential</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level 1</td>
<td>Level 2</td>
</tr>
<tr>
<td>Installation (per charger)</td>
<td>$0</td>
<td>$1,354</td>
</tr>
<tr>
<td>Site preparation (per charger)</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Utility service (per service)</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Transformer (per station)</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Equipment (per charger)</td>
<td>$0</td>
<td>$1,000</td>
</tr>
</tbody>
</table>

Table 2: Fixed cost estimates for each type of charger in USD (Lee and Clark, 2018).

We are taking these estimates to get an understanding of the costs to build out the complement. Taking these estimates as the basis for Tesla’s current fast charging network (1,533 stations and 13,344 charge points), the capital costs of this network are roughly between $980 million to $1.9 billion.
4. Introduction to Platform Literature

4.1. What Are Multi-Sided Platforms (MSP)?

We live surrounded by platforms. Facebook, Netflix, Uber, and Airbnb are only a few examples of these platforms nowadays—and these are only the obvious ones. Many other not-so-obvious examples of products or services involve characteristics of platform architectures and we can profit from understanding them as such. This is the case for EVs.

The literature on platforms first gained prominence in the 1980s through studies of products for which quality is determined by the total number of users (Katz and Shapiro, 1985). In the last almost two decades, research on platforms has increasingly focused on “multi-sided markets” in which different, clearly distinguishable groups of users (e.g., game developers and players, readers and advertisers, shoppers and vendors) play distinctly different roles, with each group or “side” serving as a magnet to attract the other side (e.g., Rochet and Tirole, 2003; Parker and Van Alstyne, 2005). However, defining platforms is not straightforward, as research has formed in various scholarly disciplines with many different definitions. The literature uses the terms “platforms,” “multi-sided platforms,” and “two-sided markets” interchangeably.

Some characteristics that form platforms:

- **Cross-side network effects:** The increased value that accrues to network participants is contingent on the number of other users in the network with whom they can interact. The net utility on one side of the market is dependent on the number of members on the other side (Katz and Shapiro, 1994, Parker and Van Alstyne, 2005).
- **The need for critical masses:** The businesses that participate in these industries have to figure out ways to get both sides on board (Evans, 2003).
- **Coordination of value-creating interactions:** Multi-sided platforms coordinate the demand of distinct groups of customers who need each other in some way (Baldwin and Clark, 2000; Gawer, 2014; Evans, 2003; Hagiu and Wright, 2011). Platforms exhibit architectural and governance rules that seek to balance platform control with the necessary incentives for platform participants to engage with the platform and generate value for one another (deReuver et al., 2017; Ghazawneh and Henfridsson, 2013; Parker et al., 2016; Tiwana, 2015).
- **Pricing and the potential for cross-subsidies:** A market with network externalities is a two-sided market if platforms can effectively cross-subsidize between different categories of end users that are parties to a transaction (Rochet and Tirole, 2003; Parker and Van Alstyne, 2005; Weyl, 2010).
- **Dependencies:** A two-sided market is one in which 1) two sets of agents interact through an intermediary or platform, and 2) the decisions of each set of agents affect the outcomes of the other set of agents, typically through an externality (Rysman, 2009).
- **Interfaces:** The core module of a system to which outsiders can easily connect and build upon in order to expand the system of use (Gawer and Cusumano, 2008; Baldwin and Woodard, 2009). As a core module, a platform not only performs the essential functions of the ecosystem but also establishes interface rules. This also appears in the business economics definition: A platform is a nexus of rules and architecture that exhibits network effects (Parker and Van Alstyne, 2016). It must be open such that third parties can exchange value and it must have governance such that participants abide by the rules (Parker et al., 2017a).
These characteristics lead to very specific challenges when building platform architecture services or products and vastly differ from linear value chain strategies (Van Alstyne et al., 2016). Some traditional insights do not apply because of the interrelationship between the sides. In this sense, Evans and Schmalensee (2013) argue that one-sided tools often do not apply, at least not without substantial changes, to multi-sided platforms.

4.2. View Electric Vehicles as MSPs

By a recent estimate, carmakers worldwide will spend about $255 billion\(^{17}\) in the five years to 2023 on developing battery-powered cars (Behrmann, 2019). Hence, getting the mechanics of how to make these investments successful is crucial, beyond the individual car maker.

Electric vehicles share many of the identified characteristics and thus are platform products rather than standalone products.\(^{18}\) Electric vehicles are technology platforms, i.e., modular technology architectures requiring complementary products and services for their operation. Most obviously EVs rely on a complementary charging network to be useful. The broad diffusion of electric vehicles relies on a new charging network that needs to be embedded in the existing electrical power network, the vehicles need to be compatible with the charging stations and the use value of the vehicle increases with the range of possibilities to be charged. Conversely, investments in charging stations are viable only when there is a sufficiently large number of EVs that can deliver high utilization and revenue from these stations. While the viability of fast-charging stations depends on many factors, one study finds that on average a fast-charging station needs eight customers a day to break even; at the moment many of them struggle to get even half of that (Behrmann, 2019). This structure brings along its very own set of challenges. Hence, EVs are facing a situation where the decisions of each group of users on either side of the market affect the outcome of the users on the other side(s), and the increased value that accrues to network participants (EVs) is contingent on the number of other groups (charging network) in the network with whom they can interact and exchange services (charging). Moreover, this value-creating interaction of charging needs to be coordinated. Most obviously the charging standard (the plug) needs to fit, but also the billing systems of both sides need to match or the coordination of available charging spots and route planning requires the coordination of the two sides. Compared to gas powered vehicles, electric cars lack a refueling infrastructure and a distribution and service network.

In the following, we want to disentangle the different forces that are at play in the BEV case from a platform perspective, shed light on the theoretical lenses, and view the challenges of the players through these lenses.

4.3. Platforms Face Specific Challenges

Platform architecture products face novel challenges and action spaces. In the next section, we dissect accompanied decisions and evaluate how actors in the BEV case have used or not used them. Many others have done an incredible work to summarize the state of the literature on platforms and multi-sided platforms (MSPs) and thus greatly informed this overview (Stummer et al., 2018; Sanchez-Cartas and Leon, 2019).

\(^{17}\) Note: This is in stark contrast to estimated investment of Tesla in its supercharger network or the announcements of governments and charging network providers that remain in the single-digit billions at maximum.

\(^{18}\) We are not the first to observe this. Several studies point to different aspects of the platform nature of electric vehicles (Li, Tong, Xing & Zhou, 2017; Springel, 2017; Papachristos, 2017).
4.3.1. How to attract two sides or solve ‘the chicken-and-egg problem’

One of the most fundamental features of platform architecture products are their two- or multi-sidedness, specifically the dependency of two or more interdependent sides. One of the most important challenges with multi-sidedness is the need to attract two or more sides at the same time.

There are many examples of the need to attract but also potent powers at play in attracting two sides. For example, the race by JVC in the 1980s to bring a wide range of hardware manufacturers on their VHS technology (Cusumano et al., 1992), the growth of IBM’s personal computer largely fed by the availability of a wide variety of software (Bresnahan and Greenstein, 1999; Langlois and Robertson, 1992), the growth of Google’s Android and Apple’s iOS operating systems and the decline of the Symbian operating system (Basole and Karla, 2011).

Since the basic premise of economic models is that competition among platform-mediated networks is driven by the adoption of the platform by both users and complementors, many studies focus on understanding how to attract multiple sides to the platform (McIntyre and Srinivasan, 2017). Most economic models have focused on pricing by platform firms (Evans, Hagiu, and Schmalensee, 2006; Parker and Van Alstyne, 2003, 2006; Rochet and Tirole, 2003, 2006; Rysman, 2009), suggesting that platform firms may subsidize one side of the platform by using deep discounts in order to attract the other side to join. Tesla, for example, acted on that blueprint by making charging free in the beginning. However, other studies focus on aspects such as entry timing of firms (Eisenmann, 2006; Schilling, 2002; Shapiro and Varian, 1998), incumbent advantages such as firm size (Schilling, 2002; Sheremata, 2004) and platform features, and relative quality (McIntyre, 2011; Zhu and Iansiti, 2012). Also, to solve the “chicken-and-egg problem” and take into account the “winner-takes-all” characteristics of platform markets, firms have strong incentives to signal and condition user expectations about their potential for future dominance or future value (Chintakananda and McIntyre, 2014; Fuentelsaz et al., 2015). Again, Tesla does a fairly good job of signaling the future value of their charging network, yet finds it difficult to credibly communicate future dominance.

A key feature of two-sided markets is that platforms must be able to attract two or more different types of users at the same time. A car without the adequate charging infrastructure has no future, and the opposite is also true.

“The demand on each side tends to vanish if there is no demand on the other side, regardless of what the price is. [...] The businesses that participate in these industries have to figure out ways to get both sides on board” (Evans, 2003, p.195).

This problem is known as “the chicken and egg problem” and several strategies have been demonstrated to provide useful solutions:

**Self-coordination:** This argument puts forward the idea of overcoming the chicken-and-egg-problem by making assumptions about users’ expectations. However, it is a risky bet to focus only on consumers’ ability to coordinate among themselves (White and Weyl, 2016). Ambrus and Argenziano (2004) state that if there are lots of small consumers on the market then it is practically impossible for them to get together and make explicit agreements on network choices. A model by Rochet and Tirole (2006) shows how coordination arises among heterogeneous consumer groups, and consumers proportionally value
the number of sellers on the other side. Then, given the prices, every consumer has a dominant strategy to join one platform. In the monopolist model proposed by Armstrong (2006), we find something similar. Consumers have homogeneous valuations for externalities, which allows platforms to promise utility levels. In both cases, platforms commit to offering consumers a particular level of utility by adjusting their price in response to changes in the number of users on the other side, fully insuring users against any change in their utility, thus giving them a dominant strategy (White and Weyl, 2016; Sanchez-Cartas and Leon, 2019).

To address the coordination problem, Weyl (2010) proposes the “insulating tariffs.” The basic idea to overcome the coordination problem is to assume that platforms choose user allocations (and not prices) to maximize some objective function. In that way, prices are an insurance instrument of utilities. Platforms charge a price on each side fixing a utility level for users. Therefore, users do not care about the size of the platform on the other side. However, if we consider a dynamic context, Cabral (2011) points out that platforms cannot fix a utility level on one side that is independent of the size of the other side because the platform does not “insure” agents, rather the platform “subsidizes” early adopters to compensate the low utility of joining the platform at that stage (Sanchez-Cartas and Leon, 2019).

Subsidizing: Another way to overcome the coordination problem was proposed by Caliaud and Jullien (2001) and Evans (2003). One way to get both sides on board is to obtain a critical mass of users on one side of the market by giving them the service for free or even paying them to take it (Evans, 2003). This strategy is known as “Divide and Conquer” because it requires dividing the market between the profit segment and the loss segment in order to conquer the market. This strategy solves the coordination problem because it creates an incentive to join the platform on the loss side, and given the network effects, that creates an incentive on the other side to join the platform. Despite the theoretical discussion about the correct way to discriminate among equilibria, this is probably one of the easiest, practical solutions to the problem, though critics argue that the coordination problem is mitigated but, sometimes, it is difficult or dangerous to subsidize users because it can attract users without their commitment to using the platform (Jullien, 2005). This possibility creates the problems of adverse selection and moral hazard (Armstrong and Wright, 2007; Parker and Van Alstyne, 2005). In addition, Parker and Van Alstyne (2005) find that sometimes it is not clear on what side a platform should charge positive prices. Therefore, the consequences can be critical because we can attract a mass of users only because there is a subsidy.

Subsidizing can take many different forms, such as price cuts, free usage, offers of investment incentives (Ackerberg and Gowrisankaran, 2006; Hagiu, 2009; Muzellec et al., 2015), offers of value-added services (Dou et al., 2016), technical support for development programming (Schilling, 2003), and even paying users as a means of attracting them (Evans, 2003). The decision as to which side to charge and how (calculation and charging mechanism) is complex and depends on factors like the users’ sensitivity to price (Hagiu and Spulber, 2013) or quality (Eisenmann et al., 2006).

Freemium: Freemium is often geared to have free users to increase the probability users on the same side or the other side adopting and paying. Greater numbers of free users on one side can increase the likelihood of other users of the same side coming to learn and appreciate the value of a product, through word-of-mouth (Dou et al., 2013). For example, DropBox gained foothold into business markets by first appealing to individual employees and buying managers of organizations. A greater base of free users on one side can analogously increase demand and adoption on the other side of the market as well as increase the willingness to pay of actors on different “sides” (Parker and Alstyne, 2005; Rochet and Tirole, 2006; Boudreau and Hagiu, 2008). Additionally, the freemium strategy can break the tension of
growth and profitability that platforms often face (Bhargava, 2014). In this the freemium strategy has multiple benefits: it segments the market indirectly, expands sales via the free version, preserves a high margin for the premium product (Bhargava, 2014). Ultimately, the free version can also act as a trial device and increase the adoption on one or both sides of the market, especially when users are a priori uncertain about its value (Bhargava, 2014, Niculescu and Wu, 2014).

**Single target group/Staging:** Focusing on one particular target group or market segment is a well-known strategy and MSPs may start, for example, with a single city or industry. By reducing the total market size and the required critical user mass, MSPs require fewer resources and less time to reach the critical inflection point from which the MSP can grow to other market segments. When initially focusing on a single market segment, MSPs can achieve higher levels of differentiation and platform performance in this market segment, which increases expectations among potential platform users that everyone else will adopt the same platform in the future (Cennamo and Santalo, 2013). Other authors argue that it is more natural to observe firms begin with a one-sided model and switch to a two-sided model as they become more established. Doing so allows potential platforms to overcome the chicken-and-egg problem (Rysman, 2009).

Additionally, with the platform-staging strategy, an MSP evolves in two distinct steps from a traditional vendor-based business model in the first stage to a platform mediation business model in the second stage after reaching the critical user mass (Hagiu and Eisenmann, 2007; Hagiu and Wright, 2015). This strategy can help MSPs to focus on one market side at a time, thereby avoiding negative indirect network effects in the early development stage. When executing a staging strategy, the platform design should be geared toward the final MSP architecture from the outset (Eisenmann et al., 2008), although a traditional business model may be applied in the first stage.

On the other hand, some authors have considered that, if the problem is to attract both sides at the same time, platforms may be interested in changing the timing. That is the proposal to overcome the coordination problem developed by Hagiu (2006). He proposes a model in which software developers arrive before consumers. This asymmetry in timing mitigates the coordination problem on the consumer side, but it does not mitigate it on the developer side. He only focuses on two equilibria. One with “optimistic expectations,” and another one with “pessimistic expectations.” In the former, he finds it is optimal to commit prices as soon as possible, but in the later, he finds the opposite.

**Envelopment:** Platform owners can achieve growth of a new platform by designing an envelopment strategy (Eisenmann et al., 2006; Eisenmann et al., 2011; Suarez and Kirtley, 2012), which is a platform strategy that builds on an already existing platform business in another market and wherein platform owners leverage this position by operating in multiple platform-based markets simultaneously. Platform operators can move into adjacent platform-based markets by combining their existing platform’s features with that of the target’s platform (Eisenmann et al., 2011). Many real-life examples show the power of this strategy in various different forms, such as when Microsoft conquered Real Networks, a once-dominant media platform, by bundling Windows Media Player with its complementary Windows platform (Wan et al., 2017). Alibaba increased the attractiveness of its business-to-consumer platform, Tmall.com, by building on and leveraging its installed base, the consumer-to-consumer platform, Taobao.com (Wan et al., 2017). Especially small companies can profit from this strategy. Small companies that typically lack a large installed base may piggyback on an existing platform and provide new services without creating a new demand (Wan et al., 2017). In the case of the room reservation service, Airbnb launched by integrating themselves into Craigslist. PayPal piggybacked on eBay before it was acquired. And the payment service, Square, launched on top of the iPhone and Android platforms.
In sum, the platform envelopment strategy aims at leveraging the shared relationships with (other) established platforms and their networks (Eisenmann et al., 2006). This is possible because many industries (such as the BEV market as we discuss below) with MSPs are neither exclusive nor do they operate in a ‘winner takes all’ market setting (Caillaud and Jullien, 2003) which allows multiple MSPs to coexist (Shankar and Bayus, 2003). Rather than building a platform from scratch, the platform envelopment strategy aims at partnering with existing and potentially large platforms with a view to growing with them (Rochet and Tirole, 2003). In addition to a substantial overlap in the user base, the platform envelopment strategy also requires low costs for switching or multihoming users (Armstrong, 2006).

**Exclusivity Agreements**: Signing exclusivity agreements on one market side can attract other users on both market sides (Cennamo and Santalo, 2013). In the gaming industry, for example, MSP providers like Sony and Microsoft mediate between game developers and game consumers. Both contracted Electronic Arts, the dominant sports game manufacturer at that time, in order to achieve some form of (temporary) exclusivity for some games that are supposed to attract both gamers and other game developers to their consoles (Eisenmann et al., 2006; Rysman, 2009; Parker et al., 2016). Exclusivity agreements have been proven to enhance the competitiveness of an MSP’s offering (Armstrong and Wright 2007; Hagiu, 2009). Moreover, exclusivity agreements with marquee users potentially increase the overall quality of content on an MSP, as they diminish the adverse selection problem of attracting lower quality content (Cennamo and Santalo, 2013).

**Side-Switching**: The idea behind the side-switching strategy is to make a two-sided platform one-sided by finding a platform design that allows users to fill both market sides of the MSP at the same time. Obviously, this strategy only works if services or products of both sides do not require high set-up costs or specific knowledge. The concept of side-switching on MSPs has already been addressed by Gazé and Vaubourg (2011).

Nonetheless, Evans et al. (2008) argue that expectations about the ownership structure are essential. If users believe that a platform is going to change its strategy toward integration, it sends a message that market is not going to fail in providing that good/service. It also sends a message that competition will be more aggressive on one side and, therefore, profits will be lower. From their point of view, integration mitigates the coordination problem, but integration alone does not solve it. In fact, integration is neither necessary nor sufficient to solve the problem.

In general, all platforms change their strategies towards disintegration when they are mature. As a summary, there are several proposals in the literature, but there is no consensus. A question remains whether there exists a universal solution to overcome this problem? Given the evolution of the literature, it seems that we will not have an answer to this question any time soon.

### 4.3.2. How to ensure to become the dominant platform

**Attracting or providing complementors**

In platforms--in contrast to product firms--the value that accrues to network participants is contingent on the number of other users in the network with whom they can interact (Eisenmann, 2006a; Farrell and Saloner, 1984; Katz and Shapiro, 1986). In platform markets the success of a platform is likely a
function of which one can attract the most (and the best) complementors. Complements describe goods and services built on a platform that enhances the value of a core good to a network via indirect network effects, such that the value of the core good to adopters is greater in tandem with the complement than without it (Brandenburger and Nalebuff, 1995; Gawer, 2009; Yoffie and Kwak, 2006; Zhu and Iansiti, 2012). A subset of these strategies focuses on the platform itself providing the first complements. While this requires larger investments, it gives the option to set quality points and expectations for both the customers and complementors. For instance, Microsoft leveraged the knowledge it gained from developing popular games for its Xbox console in-house to build a development kit worth $10,000, which it licensed for free to producers willing to develop other games for the Xbox (Schilling, 2003).

Much of the extant literature hence deals with the question of how to attract and keep complementors, e.g., through managing expectations, leveraging the installed base, ensuring profitability for partners, finding the right mix of product range and level of product quality, as well as the right level of openness. In the case of EVs, the value of the car is contingent on the availability, access and spread of the charging network. Hence, by the multi-sided platform perspective, to achieve a strong competitive position is determined by the combination of car-infrastructure system, and not only by product features of the car and the operational excellence of the manufacturer. Without understanding this mechanism, designing a winning strategy for EVs (and any other platform-architecture product) is almost impossible.

**Signalling**

It is in the nature of multi-sided platforms that the launch of a new platform comes with uncertainty about the platform’s ability to attract users from both or various sides of the market. For example, when Apple launched its first iPhone in 2007, the market responded with hesitation. Developers were uncertain about the attractiveness for end-users of the phone’s touch-screen feature (and hence uncertain about their decision to develop applications), while end-users were uncertain about the potential for new applications (and hence hesitant about buying) (Jullien and Pavan, 2017).

Given the possible dominant outcomes in multi-sided platforms, the outcome of investments of complementors and user to join the platform are uncertain and they can be stuck in the “wrong” platform with stranded investments. Hence, expectations of a platform’s growth potential can influence users’ product adoption choices (Papachristos, 2017). Given that, firms have strong incentives to signal and condition user expectations about their potential for future dominance (Chintakananda and McIntyre, 2014; Fuentelsaz et al., 2015).

Different strategies to do so have been evaluated in the literature. Platforms invest considerable resources in signalling activities, such as advertising, exhibitions, information disclosures, forums, blogs or own investments in complements, all aimed at promoting to each side of the market the platform’s ability to attract users from other sides and reducing uncertainty (Jullien and Pavan, 2017). For example, platform owners can create an initial consumer base building on in-house developed complements. This can signal to third-party complementors to expect a large future installed user base (Hagiu and Spulber, 2013; Cennamo, 2018). Also, producing in-house complements can showcase a platform’s technological potential and attract consumers to switch to it (Schilling, 2003; Sheremata, 2004). However, not all forms of signalling are helpful. Signalling only on the product level can lead to disastrous crowding-out effects by cannibalizing the current product range, also known as the Osborne Effect (Rao and Turut, 2019).

**Installed base**
As a result of network dynamics, the literature suggests that winner-take-all outcomes are possible in some platform-mediated networks as the platform with the largest number of users “tips the market” in its favor (Eisenmann et al., 2006; Katz and Shapiro, 1994; Shapiro and Varian, 1998).

“Stronger network effects of the larger installed base typically win market share. For example, when Microsoft enveloped Real’s audio streaming technology into Windows, Microsoft enjoyed more than 90% market share in desktop operating systems. Each new release of Windows caused RealAudio to lose streaming market share among content consumers and content creators because neither would pay the incremental cost of Real’s now duplicate functionality” (Parker and Van Alstyne, 2016, p. 6).

Hence, scaling and diffusion strategies in platform markets are different from product markets. Conventional wisdom suggests that network effects drive faster market growth due to the increasing returns associated with such processes (Nair, Chintagunta and Dubé, 2004; Tellis, Yin and Niraj, 2009). Incumbents can build on their installed base which creates multiple effects of previous adopters on the rate of growth. Previous users are expected to accelerate growth and, at the same time, the adoption of previous adopters increases network externalities which overall accelerates adoption. The result being that the presence of these installed-base effects, known as network externalities, makes it excessively difficult for firms to enter the market with new products or new technology (Katz and Shapiro, 1992).

However, networks also can create the opposite effect, slowing growth with what is labeled “excess inertia” (Srinivasan, Lilien and Rangaswamy, 2004). Taken together, these results suggest that installed base size alone may be an insufficient predictor of future network growth. Suarez (2005) supports this notion, finding that gross network size is a relatively poor proxy for network value and that other attributes may be contributing to the benefits of installed base in network industries.

**Product quality and product range**

Also the aspect of product quality differs in platform markets versus classical operations research for pipeline businesses. As introduced above, the number of complements plays a decisive role in many studies highlighting the importance of attracting complementors. However, some users may value diversity of complements, not merely their quantity (Zhu and Iansiti, 2012). Authors also find that a platform with lower capabilities but a wider product mix might be a winning strategy in a network with cross-side effects that is content driven and highly competitive (Anderson et al., 2014). Some have argued that a small lead in attracting early customers could tip the market in favor of an early entrant with an inferior product or service (Cowan, 1990; Shapiro and Varian, 1998; Sheremata, 2004; Wade, 1995). Hence advocating for lower product quality but faster market entry. Contrary to that, another stream of research holds that product quality is an important determinant of success in platform markets, and that dominant platforms tend to be those that exhibit the highest quality (Liebowitz and Margolis, 1994, 1995; McIntyre, 2011; Tellis et al., 2009). Indeed, it has been shown that high-quality complements, generally referred to as “hits” (Corts and Lederman, 2009) or “superstars” (Binken and Streimersch, 2009), can critically affect platform adoption (Cennamo, 2018).

Outlining the mixed results on the mechanisms of product quality in platform markets highlights the uncertainty for actors of making decisions about product quality. Thus, in assessing the value of a platform to users, one should account for both variety and quality of complements (Panico and Cennamo, 2015).
4.3.3. Platforms do not optimize value chains

In traditional industries, bilateral exchanges follow a linear path as firms purchase inputs, transform them to add value, assemble components and subsystems into complete products, and then sell the output. In platform industries, interaction follows a triangular relationship (Eisenmann et al., 2009) as parties first affiliate with the platform then connect or trade using platform resources. In general, this networked way of creating value has been identified as one of three elemental configurations through which firms generate value (Thomson, 1967; Stabell and Fjeldstad, 1998). Next to this, platform architecture products are very different from classical pipeline products (i.e., linear value chain thinking) as both sides can incur costs and accumulate revenue (Parker and Van Alstyne, 2016).

Second, in a platform, actors are much more interdependent than in pipeline businesses and resources are shared to a large extent. It is common (or often essential) for platform operators to access and leverage external resources and capabilities owned by other agents in a platform system. Platform logics require a switch from owning resources to the orchestration of resources, from optimizing supply chains and internal productivity to facilitate external interactions, and from optimizing product and customer value to ecosystem value (Van Alstyne, Parker, Choudary, 2016). This broader conceptualization implies that platform owners should pursue aggressive, costly, and ultimately risky growth strategies aimed at attracting large numbers of complementors (Garud, Kumaraswamy, and Langlois, 2009); Gawer and Cusumano, 2002; Schilling, 2002; Boudreau and Jeppesen, 2015).

This broader view of resources coincides with the fact that platform owners compete at an ecosystem level, which means that the success of their platforms depends on an ecosystem’s resources rather than those of a platform (Wan et al., 2017). Hence, strategy becomes vastly more complex as firms consider dynamic interactions of a multi-layered business ecosystem (Parker and Van Alstyne, 2016).

“The sheer number and complexity of instruments being used by platform owners, including investments, technology rules, information dissemination, contracting choices, and pricing, is an empirical phenomenon deserving closer attention and clearer explanation” (Boudreau and Hagiu, 2009, p. 25).

In addition, it is vital in platform architecture products to understand and assess the value of the whole system (the platform and its complements, compared to the single product) in relation to other competing systems (Cennamo, 2018).

Accordingly, to this extension, the levels of competition get extended as well. Competition in platform markets occurs at three levels of a platform ecosystem (Parker and Van Alstyne, 2016). It exists from one platform to another, as in the video game console battles of Sony, Microsoft and Nintendo (Evans et al., 2006). Competition also can exist between a platform and its partners, as in the case of Microsoft appropriating such partner innovations as browsers, multi-threading, streaming media, and instant messaging into its operating system (Jackson, 1999; Nalebuff, 2004). Finally, competition can exist among partners each vying for position within a focal platform, as in the case of two games reaching for the same consumers on the same console (Boudreau and Hagiu, 2009; Markovich and Moenius, 2009). 

Managing these multiple levels of competition is a dynamic problem owing to the need to cooperate as well as to compete (Parker and Van Alstyne, 2016).

Very concretely, from a product strategy perspective, Sun, Xie and Cao (2004, p. 244) identify four alternative product strategies available in markets with network effects:
1) A single-product-monopoly strategy, under which the innovator is the exclusive seller of the product based on its technological standard;
2) A technology-licensing strategy, under which the innovator creates compatible products externally by licensing its technology to competitors;
3) A product-line-extension strategy, under which the innovator internally creates compatible products with multiple qualities; and
4) A combination strategy, under which the innovator simultaneously licenses its technology and expands its product line.

All of the product strategies identified by Sun et al. (2004) aim at the question through which level of openness (chapter 4.3.4) the necessary attraction of complementors (chapter 4.3.1) can be achieved. Thus, this notion links the product strategy level with the platform lens and points to the increased importance of product strategy decisions in platform architecture products. Further, in contrast to pipeline businesses, in platform business the platform owner not only must care about its own profits, but also about the profitability of the ecosystem of complementors. Cennamo and Santaló (2013, 2015) argue that a platform system that offers only limited profitability for the participating complementors becomes a “market for lemons” (Akerlof, 1978) in the long run.

4.3.4. Governing Openness

A core feature of platforms or platform architecture products is that they are not standalone, but interdependent, often building on a whole ecosystem of partners. Naturally, platform governance, which is generally defined as who makes what decisions about a platform (Tiwana et al., 2010), plays a particularly important role for platform owners. Platform governance makes deliberate choices about platform openness, access, ownership, and control when appropriately involving and engaging developers of complementors and in which form.

“Platforms are usually proprietary in that the technologies on which they are based are protected by patents or copyright, but they can differ in the extent to which other organizations are allowed to act as complementors. They may be completely closed to third-party access, which would be typical for a product platform meant only for in-house use. At the other extreme they can be open, like Facebook’s open server standard that was released for use by other firms to stimulate complementary activities and lower prices. Many hybrid models are also used, such as Alphabet’s Android operating system, which can be used and enveloped by smartphone firms but modified only by Alphabet. While openness adds the power of alliances, it often also reduces the opportunity for value capture through direct means. While Alphabet makes little or no money directly from the use of Android by phone makers, it captures significant value from advertisers and, increasingly, from consumers transacting within Android-based apps” (Teece, 2017, p. 215f.).

Thus, platform openness reflects the trade-off between retaining and relinquishing control over a platform (Wessel et al., 2017; Benlian et al., 2015; Boureau, 2010; Cusumano, 2010b; Ondrus et al., 2015; Wareham et al., 2014). Opening a platform can spur growth by harnessing network effects, reducing end-user fears of lock-in, and stimulating downstream production. At the same time, opening a platform typically reduces user switching costs, increases forking and competition, and reduces the
sponsor’s ability to capture rents. Empirical estimates of innovation based on level of openness exhibit an inverted U-shape (Boudreau, 2010; Laursen and Salter, 2006), suggesting that firms can optimize their levels of openness. Further, opening a platform can secure third-party participation and contribution, thus exploring new market opportunities. Closing a platform can protect the platform owners’ exploitation of internal resources. In this way, platform owners face managing the delicate balance between exploration and exploitation (Wan, Cenamor, Parker, and Van Alstyne, 2017). According to Wan, Cenamor, Parker, and Van Alstyne (2017, p. 6), “Moreover, platform owners can take a step further and facilitate, or limit, participation in the ecosystem based on inter-platform compatibility decisions. In other words, platform owners may determine whether members of its ecosystem are allowed to interact with participants from other ecosystems (Rysman, 2009; Farrell & Saloner, 1986; Chen and Liu, 2005). Specifically, platform owners also may determine whether agents “on board” a platform can enter other platforms (multihoming) or if their participation must be exclusive (singlehoming). In this sense, compatibility implies rules for interfaces to ensure that a platform’s features fit well with those of other platforms, thus making them accessible to more agents (Chen and Liu, 2005).

Platform openness can be further refined in horizontally and vertically opening as Benlian et al. describe:

“…[O]pening a platform horizontally means giving up some control by licensing the platform to additional platform providers...On the other, granting third-party complements access to the development platform and sales market of complementary applications is regarded as vertically opening a platform (Boudreau, 2010)” (2015, p. 211).

Overall, it is widely accepted that choosing the optimal level of openness is critical for firms that create and maintain platforms (Boudreau, 2010; Chesbrough, 2003; Eisenmann et al., 2009; Gawer and Cusumano, 2002; Gawer and Henderson, 2007; West, 2003). In this respect, it is a particular challenge for platform providers to determine the appropriate level of platform openness, which is the degree to which platform providers grant access to outsiders. Platform openness can be shaped through various platform governance mechanisms, of which deliberate regulations and rules about access and boundary control are key components to appropriately engage other platform stakeholders (Benlian et al., 2015; Ghazawneh and Henfridsson, 2013). Prior studies have shown that several aspects of platform openness are important evaluation criteria for developers when they think about contributing to and engaging on a platform (Qiu et al., 2011; Ghazawneh and Henfridsson, 2013). Meanwhile, owners should be prudent enough to reject low-quality complements and avoid crowding effects that will lead to negative experiences from end users (Zhu and Iansiti, 2012; Boudreau, 2012). In this respect, platform owners can exploit the resources of their platforms by keeping a limited group of members that fit a specific list of requirements (Gawer, 2014).

However, Benlian et al. (2015) show that openness of platforms can come with specific challenges. They show that opening a platform vertically and the resultant loss of control could pose problems for a platform provider in at least two respects. First, the coordination of resources becomes more complex, simply because more players and interests are involved (Almirall and Casadesus-Masanell, 2010). Second, by delegating the production of complements to external developers, the platform provider also loses control over the assortment and content of complementary platform features provided to the platform and, as a result, over the integrity and strategic roadmap of the platform (Boudreau, 2012).

Openness can be more than access, however. Openness also can be conceptualized as devolving control (Boudreau, 2010) or what Nambisan and Sawhney (2011) call decisional openness. This involves the
degree to which the innovation decision rights and, by extension, the strategic direction of the platform itself, are distributed among ecosystem members.

“Opening up platforms creates opportunities within ecosystems for entities other than the platform leaders (Bogers et al., 2017). In particular, the platform can become a venue for entrepreneurial pursuits as opportunities are identified and pursued to create complementary products or services that become part of the platform’s ‘orchestra’ (Zahra & Nambisan, 2012). Complementary products are ones in which the value of the two products together is greater than the sum of the individual values alone (Gawer & Cusumano, 2014). We know that the existence and expansion of complementary products can greatly impact the viability of the overall platform ecosystem. For example, Facebook’s success relative to MySpace has been partially attributed to its decision to open the platform to third-party developers, who built popular games and other valuable features on top of Facebook, while MySpace kept all development in-house (Parker & Van Alstyne, 2017)” (Eckhardt et al., 2018, p. 372).

Two strategic decisions have to be made, these are 1) how much of the core platform to open in order to spur developer innovation, and 2) how long to grant developers the right to benefit from sales on top of the platform before the platform absorbs those innovations into the core (Parker, Van Alstyne, and Jiang, 2017).

5. Understanding Actors’ Decisions in the BEV Market

In this chapter, we build on the two previous chapters and outline important decisions faced by the key participants in the industry (e.g., manufacturers, industry consortia, policy makers), and then critically examine the choices made using the lenses provided by the platform literature. It is useful to separate these decisions along three levels: 1) those made by individual firms (automobile manufacturers, charging network providers, etc.), 2) those made by industry bodies (CHAdEMO, EU, etc.), and 3) those made by regulators and policy makers. We aim to provide an analysis of the unbalanced investment outcomes of hundreds of billions of dollars of investment in BEVs and single-digit billions in charging infrastructure.

1) Firm-level considerations: We discuss, for instance: (a) automobile design - perfectly engineered car vs. the functioning system, (b) strategies for solving the chicken-and-egg problem, (c) strategies of specialization vs. integration, (d) the relevance of product quality and range, (e) signalling and pre-announcements, and (f) how to establish and leverage advantages and disadvantages of being an incumbent or entrant.

2) Industry-level considerations: We discuss, for instance, the establishment of standards, how to encourage the formation of consortia, and the challenges of platform coordination associated with consortia.

3) Policy considerations: We discuss, for instance, the deployment of subsidies, targets and other incentives, the paradox role of standard setting as simultaneously enabling and constraining. As products characterized by network effects are highly susceptible to “tipping” or standardization, actions of policy setters can have game-changing effects. How
will the various actors work to influence government policy? This flips the policy level analysis to a company-level decision.

5.1. Platform Launch and the Chicken-and-Egg-Problem

The chicken-and-egg problem is one of the most fundamental problems when launching platform products, covering how to mobilize both the demand and the supply side and how to coordinate between them. Platform products always rely on some other side to be valuable, which makes it essential to mobilize the two sides at the same time.

The need for this active coordination and the prevalence of the chicken-and-egg problem has been a recurring topic in many industries before. Amongst them are examples such as video cassettes and video recorders, video consoles and video games, marketplaces such as eBay or Craigslist, matchmakers such as Tinder or OpenTable, payment systems such as Visa or Mastercard, instant messaging such as AOL or WhatsApp, operating systems and software or applications, ride hailing platforms such as UBER or Lyft, sharing platforms such as Airbnb, social networks such as Facebook or LinkedIn, and so on.

Literature and practice alike identified some general strategies for how to approach this problem. The usefulness of these approaches can be evaluated against common criteria:

- **Profitability**: Does the strategy ensure profitability for both sides, in total and across time?
- **Growth**: Does the strategy enable balanced and sufficient growth (e.g., through interoperability and standards)?
- **Capital Intensity**: Is the strategy suitable given capital endowments of a single player?
- **Innovation**: Does the strategy permit ongoing innovation?
- **Operational Efficiency**: Does the strategy favor operational efficiency (e.g., driven by real time data layer)?

5.1.1. Four main platform launch strategies for BEVs

In the case of BEVs this means getting people to buy BEVs in the absence of a charging network, and, conversely catalyzing investments into creating a charging network in the absence of a large installed base of EVs. To achieve this, four different basic strategies to tackle the chicken-and-egg-problem can be distinguished that make specific strategies more or less accessible:

1) **Do it yourself**: Organizations trying to build platform products can invest on both sides themselves, which typically requires extremely high investments. In this strategy, players can further decide to begin with launching one side and then add the other side to stage investments or to launch both sides simultaneously. However, even with infinite capital, the do-it-yourself strategy bears the risk of delay in feedback. Building out a charging network takes time. For BEVs, Tesla follows this strategy.

2) **Form consortia**: Another option is to form multi- or bi-lateral cooperation agreements with suppliers of the other side. These agreements typically are aimed at reducing investment risks for all sides as their own side can build on the other side's installed base and vice versa.

3) **Regulators and policy makers**: Organizations can try to rely on governments to invest into the other side of the platform.
4) **Market:** Finally, actors on one side of the market can rely on market mechanisms to supply the other side of the market and use investment information signals to third parties as coordination mechanisms. In the U.S., for example, independent charging infrastructure providers such as Betterplace, Chargepoint, and EVgo, to name a few, built charging networks in order to profit from the growing BEV installed base.

These strategies are not mutually exclusive and can change over time. Consider the smartphone industry. In 2013 Microsoft was fighting hard to push its mobile operating system and relied on, and subsidized, external hardware makers such as Nokia to build attractive smartphones. In 2013, Microsoft chose to vertically integrate and it purchased Nokia’s handset business. Meanwhile, Apple’s phone business has primarily involved substantial vertical integration and a fairly closed platform: Apple not only makes the operating system but also is the sole producer of Apple smartphones, owns the content store, makes many apps, and even sells accessories such as earbuds. Apple CEO Steve Jobs was initially against the idea of an app store, but was convinced by other Apple executives who feared a repeat of Apple’s losing strategy against Microsoft in the desktop computing war (Isaacson, 2011). Google, Apple’s chief competitor in smartphone platforms, has primarily focused on the operating system (Android) without exhibiting aspirations for smartphone leadership, relying instead on a consortium and market-driven strategy or hardware and accessories, with occasional efforts to produce notable hardware (such as the Pixel phones). In the case of Chromebooks, Google has similarly focused on the Chrome operating system, encouraging third-party developers to produce hardware, but also producing a limited range of its own Chrome tablets and laptops.

In the current case of BEV deployment, we see all these strategies used or called for. Tesla follows a ‘do it yourself’ approach and builds the installed base of cars and charging infrastructure. With this strategy, Tesla was able to make quicker and better decisions on both sides of the market, which is critical during the early and growth phase of a company. Also, as building the charging network most likely works best by optimizing integration with the car, the ‘do-it-yourself’ approach decreases frictions as compared to the other strategies and, moreover, subsidizes one side. Tesla, for example, can mix revenues of charging infrastructure and selling cars, whereas independent providers need to develop business models based purely on offering the charging infrastructure. The integrated model also allows for higher degrees of freedom in terms of incentivizing one side. The free charging for Tesla owners is a classic launch strategy in two-sided markets. Moreover, Tesla can decide on its own which level of openness of the system they offer (e.g., one-way compatibility in favor of Tesla owners). On the downside, the ‘do-it-yourself’ approach requires massive investments (as can be observed by the cash needs of Tesla) (Hull and Recht, 2018), runs the risk of being outperformed by a joint action of another consortia, and faces the risk that other competitors gang up against you. Additionally, it runs the risk of settling on an inferior standard. This, for example, could be observed in the process of setting standards for digital telecommunication in the 1980s and 1990s. In Europe, standard setting bodies mandated a single standard for the second generation of telecommunication. In contrast, in North America the approach has been to allow the market to determine the best standard (Gandal, Salant and Waverman, 2003). Despite the initial lead of GSM through the broad diffusion in Europe, CDMA succeeded (Gandal, Salant and Waverman, 2003).

On the other hand, many OEMs formed large consortia with other OEMs to include the car and charging infrastructure side (e.g., CHAdeMo). This has the advantage that you can leverage multiple adjacent installed bases and use this as a signal to attract the charging infrastructure complementors to join this large supply. Further, consortia have the advantage of typically joined and, therefore, larger financial resources to lift the investments. On the flipside, this way of coordinating the different sides of the
market requires consensus and runs the risk of slow decision making. As already explained, many tactics rely on incentivizing one side of the market, for example, by giving the service for free. In a consortium of independent legal entities with different business models, figuring out the mechanisms of cost and revenue sharing over time is an impediment to running such consortia. Moreover, consortia bear the risk of organizations freeriding.

Additionally, one strategy is to rely on government investment in one side of the market. This has been the case with BEV charging infrastructure. For example, in California, 38% of charging outlets are financed by the state (Spulber and Smith, 2018) and a coalition of U.S. western states invests to establish a network of fast charging infrastructure along 5,000 miles of highway (Spulber and Smith, 2018). In the U.K., the industry (BP, National Grid, ABB, BYD, Siemens, amongst others) called for the U.K. government to take action on fast charging infrastructure (BP, 2019). The advantage of this strategy is the ability to define nationwide (or in the reach of the respective governing body) standards. For example, the EU defined the CCS standard, as well as China, who defined a single nationwide standard. Governments have the ability to encourage growth of charging stations through mandates, targets or subsidies which are similar tactics as used in the integrated approach. Additionally, the standard setting competence leads to fewer chances of standard wars and, therefore, higher chances of quicker adoption. On the other side, the need for consensus and clashes of authority in federalist systems lead to the risk of slow and inconsistent decision making.

Finally, relying on the market to supply the other side of the platform typically is said to have a higher innovation potential but at a higher risk. For example, we see different business models to be tried and also different technological standards to be tested (from core functions such as battery swapping versus charging to billing technologies). The downside of this strategy is the difficulty in coordinating capacity and deployment decisions. For example, it is far harder for an independent provider to decide where to install charging stations and how many, compared to, for example, the integrated model. The independent provider has difficulty determining if other providers are planning to install infrastructure in the same area or how high the demand is. On the contrary, Tesla (by also knowing the future demand of their cars through pre-orders) can build out the network according to future demand and optimize the operations in real-time by using data from their cars. Moreover, as already introduced, independent providers have smaller margins to coordinate the pricing of the two sides. To address these coordination issues, independent providers could cut bilateral or multilateral deals with OEMs. Such deals have been frequently used between network carriers (e.g., T-Mobile) and streaming services (e.g., Netflix or Spotify) or social networks (e.g., Facebook) where the data used on these services was not counted toward the data plan. This is a classic example of differential pricing through bilateral deals of independent but complementary providers.

**Another launch strategy**

Another launch strategy especially effective when heavily planning on building both sides at the same time on one's own is to focus on the least price sensitive segments to assure high margins to cross-finance the other side of the market. Tesla started in the upper class market of cars and moved to mass market cars later on. On the contrary, OEMs focused on mid-level mass market cars. Taking a platform perspective, this strategy is reasonable because it aims to build an installed base. However, the strategy to start at the top with a price insensitive segment contradicts the plan to build a large installed base early on to create platform growth and become the dominant platform (see chapter 5.2.4).

Overall, in the case of the EV, the coordination problems appear to be so dominant that the pros of an integrated ‘do it yourself’ approach outweigh the disadvantages. On the other hand, other factors may
have influenced Tesla’s approach from a platform theory perspective. At the beginning, Tesla had the following choices:

- **Build electric vehicles and rely on the market to provide the charging infrastructure**: In this case, Tesla would be faced with the situation that the only possible source of revenue can be generated from selling cars, which puts a lot of pressure on operational excellence production in a Californian plant of the 1980s. Additionally, the supply of the much needed charging infrastructure (and in reverse the demand for Teslas) would be highly insecure.

- **Build electric vehicles and at the same time cut deals with independent charging providers or form other consortia**: Despite the general lack of such players in 2012, this strategy would additionally bring the risk of standard clashes, less possible innovation on the charging on the car side and little to no influence on the deployment decisions of the charging infrastructure (e.g., infrastructure is built and Tesla sales are asymmetric). Also, history proves Tesla right. In hindsight, the relative ineffectiveness of the formed consortia to roll-out new charging infrastructure and charging mode innovations shows the disadvantages of this strategy in the given platform product market.

- **Build electric vehicles and rely on regulators and policy makers to build the charging infrastructure**: As governmental bodies did not signal that they would do so, it would have been a high risk strategy.

Taking these counterfactuals, Tesla’s strategy to compete on both sides of this platform market and simultaneously build cars and charging infrastructure (to be precise, with a time-lag of about one year) was the most promising amongst the given alternatives for Tesla. And the long relative inaction of its competition made this strategy successful.

**Underutilized alternatives to launch**

Overall in the case of BEVs the available action space to solve the chicken-and-egg-problem for platform products is not fully leveraged in the industry. On the one hand, **differential pricing** or subsidizing could be used to a larger extent. For example, the car side could be bundled with other underutilized charging stations, or real-time differential pricing for load balancing could be introduced. Conversely, the relevant players do not seem to fully leverage the existing **installed base** of other firms with a physical presence, such as 7elevens.

Additionally, a known strategy to solve the chicken-and-egg-problem is **staging**. The development of BEVs followed a staging strategy. The first generation of cars were hybrids with a battery pack as an adjunct to a traditional gasoline car, and the next was full-electric vehicles (which were totally dependent on charging stations). Meanwhile, the first manufacturers of the hybrid cars also introduced plug-in hybrids whose battery pack was charged at a charging port. Superficially, this sequence seems reasonable. The first generation had no need for the second side of the network; and the second generation could then follow once the network was established.

Imagine instead if the first category were plug-in hybrids. These would not suffer from the chicken-and-egg problem because people could buy them even in the absence of a charging network, yet they would start creating demand for charging. Then, once you got a million cars, that would attract investments for
building a network. That, in turn, would make space for all-electric vehicles. In fact, under this sequence it would be most likely that the charging network for plug-in hybrids evolved as a “public” network (rather than proprietary to one system as Tesla’s became) and that the transition to all-electric cars would then maintain a shared public infrastructure for charging (versus the fragmented and non-interoperable networks that we see today).

However, this sequence did nothing to mitigate the chicken-and-egg-problem. One approach to address the chicken-and-egg problem with sequencing is (a) first to establish a large installed base on one side of the market, by ensuring that this side gets sufficient value even in the absence of the second, and then (b) to employ the installed base as an incentive to drive investments into the second side. The first generation hybrid cars seem to fit this. They were desirable as lower-emission vehicles and could fully utilize the existing gasoline fueling network (step (a)). But, while quite successful as a car, they actually did nothing to advance step (b), i.e., the installed base of hybrids did not create any demand for charging stations because their battery pack is charged by gasoline in the tank. Indeed, when firms began launching full-electric EVs (e.g., Nissan LEAF) the absence of charging networks was a tremendous disincentive for purchasing the car despite its visible advantage as a green vehicle. This became a serious problem for the first few EV-makers, further amplified by their lack of deliberate action to create charging networks.

Moreover, in general we did not see attempts to build an open architecture platform ecosystem that leverages the power of many external providers. Although many independent charging infrastructure providers exist, there is a surprising inaction to govern this openness (see section 4.3.4 ).

5.2. Aiming for Growth and Potentially the Dominant Platform

Once the BEV industry overcomes the initial platform launch hurdle and solves for the chicken-and-egg-problem, platform players will try to grow the platform on both sides as this disproportionately increases the utility of the platform overall. Business jargon tells us that markets with network effects end in winner-takes-all situations as eventually users and complementors will concentrate on one platform—the biggest one. Different strategies can be employed to achieve platform growth, however, as not all platform markets are WTA, a critical examination of this characteristic needs to take place first.

5.2.1. Do we observe a winner-take-all-market?

An interesting phenomenon in two-sided markets is that sometimes the winner seems to take the entire market, whereas in other markets multiple networks can co-exist and share the market. In the example of PC operating systems, VCR formats and typewriter keyboards, etc., one network takes all or almost all of the market. In this case, it is likely that one platform will become the dominant one. On the other hand, we don’t always end up with one single platform dominating the respective market. In the two-sided market of credit cards, four major payment networks have been competing for a long time already (VISA, MasterCard, American Express, and Discover).

In order to understand if a market is likely to tip toward a winner-take-all market, various factors play a role (Eisenmann, Parker, and Van Alstyne, 2006):

- **Strength of network externalities**: How much does one side profit from users on the same side (direct network effects) and on the other side (indirect network effects)? In the case of EVs we can observe several particular direct network effects in certain circumstances. Increased data
sharing between the EVs about routes and charge status will drive improvements that optimize the overall system for consumers. For example, waiting lines at chargers could be bypassed. However, more important in this case are the indirect network effects between charging infrastructure and cars. These are especially in the beginning quite dominant but heavily decrease over the course of building out both sides. Additionally, consumer preferences regarding the charging infrastructure can be assumed to be homogenous (e.g., easy and fast). Consequently, product differentiation considerations cannot trump network effects and it is unlikely that multiple incompatible differentiated networks will coexist.

- **Switching costs and multihoming**: How much does it cost for an EV customer to get access to another charging network (switching) or to have access to multiple charging networks (multihoming)? In general, especially on the fast-charging level 3 hardware, incompatibility leads to higher switching costs and it is difficult to multihome. However, we see already today that Tesla offers hardware adapters to the European CCS system, making it possible to access other charging networks. On the lower charging levels, general compatibility can already be assumed today. Both factors argue against the possibility of a winner-take-all market. Additionally, especially on the fast-charging level 3, charging-infrastructure communication protocols are a soft component to increase costs of (or even prevent) switching. However, as seen in other industries such as ride-hailing services, multihoming is oftentimes hard to prevent.

In summary, we do not assume that in the long run the BEV and charging infrastructure MSP will yield a winner-take-all market, particularly because the two-sided market ultimately heavily depends on the car side. However, there will likely be a dominant network for some time where this dominant position can be exploited. From this long-term perspective, the strategic choice of OEMs to only focus on the car side makes sense if they assume that the dominant network will only be there for a short time.

### 5.2.2. Data can move the needle

However, the analysis above can change direction under the assumption that route planning and charging station optimization become a source of competitive advantage. This can be the case because of the general undersupply of charging infrastructure or the lack of otherwise viable standalone business models for charging infrastructure. The underlying mechanism is that information about both charging infrastructure and car utilization (e.g., routes in time) can compensate for either too little demand for charging or congested charging stations. The more these data are centralized, the better this optimization can be, which leads to more winner-takes-all structures in immature markets. Much as in cases of the sharing economy, the real-time information about demand and supply decreases the idle time of resources. Therefore, building a data layer that connects both sides (the car and the infrastructure) could, for a certain period, offer the best value to customers and generate positive feedback loops on both sides, favoring winner-takes-all markets. Building this data layer requires direct real-time data from cars and infrastructure, as well as IT-alignment between these infrastructures. History shows that this is best done in an integrated model where both sides are designed and operated by one party.

### 5.2.3. Signalling

Another strategy for growth through attracting complementors is to signal the future dominance of one particular multi-sided market. The general idea is to signal to one particular side (compared to competitors) that it makes more sense to join one’s own system than the others. This is because customers’ expectations (will the platform offer the best utility in the future) and complementors’ expectations (will the platform be the most successful) are important in attracting more users and
becoming a dominant platform. Signalling on one side (e.g., to become the dominant BEV standard) should attract investments of complementors. When VW presents a BEV roadmap and estimated sales forecast, investors of charging infrastructure build on this information by investing in charging infrastructure in order to profit from the future demand of charging infrastructure. From an economic perspective, that vehicle manufacturer’s and charging station provider’s decisions cannot be viewed isolated but depend on each other creates the problem of multiple possible equilibria. Because of this firms have an incentive to influence and coordinate the expectations of consumers such as creating BEV roadmaps and forecasts.

Signalling in multi-sided markets is challenging. For example, signalling only at the product level (as many of the OEMs are doing) does not make much sense, as the customer is interested in the combined utility function of car and charging infrastructure. Also, signalling can cannibalize the current product range and lead to adverse effects, also known as the Osborne Effect (Rao and Turut, 2019). Among the famous examples of the Osborne Effect are Sega Corporation’s announcement of Dreamcast (next-generation game console) in 1998, RIM’s (Research In Motion) announcement of Blackberry 10 in 2011, and Nokia’s announcement of Windows Phones in 2011 (Rao and Turut, 2019).

Tesla very early announced the introduction of the Model 3 as an affordable BEV in the range of $35k. While this signal helped to attract complementors of charging infrastructure who expected a strong rising future demand for Tesla charging (e.g., the Destination Charging), it cannibalized the existing high-end products (Tesla Models S and X) and created a false anchor in consumers’ minds. When the actual product was introduced it came out in the $55-60k range. Similarly, these created expectations also did not materialize for complementors who built on the prospects of a higher demand for Tesla charging based on the sales signals. On the other hand, the information Tesla gained through pre-orders was very beneficial to plan the deployment of the charging network. Tesla additionally signalled that their platform was destined to become the dominant platform through opening their patents to offer an open standard. Industry analysts argued that opening the patents was a competitive move against the competing technology platform of fuel-cell vehicles to signal complementors, such as Panasonic, to stay invested in the more promising Tesla technology (Bin Hu, Hu, and Yang, 2016).

In summary, in platform product markets, the strategy of signalling becomes extremely delicate. It is a useful strategy to attract consumers on both sides, increase utility, and tip the market to the ‘right’ equilibrium. However, it runs the risk of strong product cannibalization.

5.2.4. Building on an installed base and fixed cost assets

For platform products that are characterized by network effects the decision by consumers regarding which network to join depends not only on the specific product characteristics and prices, but also on the expected size of the network. Typically, the current size of the network, also known as its installed base (IB), is often used as a signal to consumers of its future size. This is because uncertainty over being stranded makes consumers reluctant to join new networks with small IBs. Firms that can build on an installed base on one or both sides of the MSP have a natural advantage as the MSP already has an initial value and the IB naturally attracts complementors. Understanding how players can leverage their or adjacent IBs can be a useful perspective in understanding competition in platform markets. In the case of EVs, three obvious classes of actors could leverage their IBs:
- **Utilities and electric service providers**: In general, EVs technically build on the vast installed base of the electric grid. In theory, every lamppost or garage-plug functions as a BEV charging spot for level 2 charging and each substation can deliver enough power for level 3 and above. Utilities, electric service providers and distribution network service providers could leverage this installed base.

- **Fueling stations**: Fueling station providers already own and operate infrastructure in places that are critical for the mobility system.

- **OEMs, dealer network and employers**: All the fixed cost assets such as parking spaces could be repurposed as electrical charging stations. Employees park their cars idle for about 8 hours a day. Or car dealerships could build a shared fleet of workshop replacement cars for customers who bring in their cars for maintenance. Employers could even partner with OEMs like Tesla to create a business out of providing charging infrastructure instead of offering it as perks to their employees.  

Although, theoretically, many actors could leverage an installed base in the case of EVs, most of them find themselves trapped in the chicken-and-egg problem. Utilities and electric service providers wait for the demand from cars and until a dominant standard emerges before investing in a typically low-margin low-volume business (compared to their traditional business). The same applies for fueling stations. OEMs, the dealer network and other employers typically do not see charging as their business. That left the existing IBs that could be leveraged as an untapped resource and allowed a newcomer without any starting advantage to build an IB.

Hence, as none of the other players was able to leverage its installed base thus far, Tesla was able to build the strongest combined (car and infrastructure) IB. At this point, the rolled-out IB enables Tesla to profit from this strong position to attract more and more external complementors. For example, the installed base of cars including a proprietary charging system attracts hotels and malls to invest in Tesla’s Destination Charging system. Complementors that plan to make investment decisions into the charging infrastructure take into account their expectations about which network now and in the future will be dominant to avoid stranded assets. The IB is an important parameter to evaluate this. Additionally, Tesla might be able to leverage the synergy between the ownership and IBs of solar cell installations (via SolarCity) and BEV owners IB of its car and infrastructure system to include it into the electricity storage and renewable energies production system.

### 5.2.5. Attracting or providing complement(ors)

One critical action in platform product markets is the sustaining attraction of complementors because only with complementors do the products becomes really valuable. In general, OEMs failed to successfully attract complementors (the charging network) or take other steps to ensure a sufficiently robust charging infrastructure. However, fortunately, the industry did not engage in a lengthy, fierce and costly standard war. Early on OEMs formed alliances and signalled their preferred standard making it easier for complementors to decide on their investments. Also, standard setting bodies early on decided

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19 These actors on the other hand find themselves in another MSP structure. The EVs could function as load balancing for the variation in electricity supply that is induced in the system through increasing shares of renewable energy.

20 In contrast, charging stations have mostly been set up in shopping malls and retail locations (Blaesser & Negro, 2019) even though in some sense these are not as well suited as workplaces as shopping doesn’t take as much time as a day job and there is a lot less predictability about it.
on standards (e.g., with the CCS in the European Union). However, for complementors to invest and develop charging infrastructure, much uncertainty remained and prevented investments and the build-up of a powerful complementor network. Many decisions in this platform context are interrelated making investments less forgiving or flexible than in platforms such as software development. Complementors must decide where to place charging stations, how many, and at which levels of charging. All of these decisions have interrelations to other complementors (Is a competitor planning charging infrastructure close by?) and OEMs (What size will batteries in future cars be? Will EVs be designed for local urban commutes or for long-distance highway travel?). The failure to coordinate the many decisions results in a general unattractiveness for complementors to invest.

Tesla’s strategy is entirely different. Tesla did not set out to attract complementors. Rather, Tesla built the complementing product on its own, which allowed Tesla to reduce much of the information asymmetry and reduce the investment risk. Tesla now can strategically position the complementary product that best fits its current and future car features, and can align network and route optimisation between car and infrastructure. Additionally, by leveraging the IB, Tesla also was able to attract some external complementary charging with its Destination Charging. The strategic question now facing Tesla is when and to what extent to open the platform (especially the complementor-side)?

5.2.6. Product quality, product range and timing

Another important question in platform product markets is product quality (quality of vehicle as a single component compared to the platform quality) and the range of products offered (broad versus narrow). In networked markets, decisions on product quality, product range, and timing can be very different from standalone products. That is because a firm’s network size determines the network benefit for an existing or potential user. Thus, the network becomes a fundamental asset linked to product quality and customer utility (Bhargava et al., 2014). Network effects drive up the importance of a large installed base, and make versioning and product line expansion more attractive. For goods with network effects, having an expanded product line with multiple versions can help resolve the conflict between growth and profitability (Bhargava and Choudhary, 2004). How should the firm approach product line expansion under the presence of expansion costs and uncertainty about developer participation?

In the BEV case, very different strategies regarding product quality and product range are observed. The OEMs are generally focused on a very high quality of the car component and put comparably lower emphasis on the combined product quality of charging system and car together. The assumption here is that OEMs in general plan to make money on the car side only. The product mix is rather limited. This limited product mix of incumbent OEMs leaves space for newcomers to access the market with their own offerings.

On the other hand, Tesla has a comparably lower quality of car but offers a higher platform quality with the extensive charging network and all its additional charging features. Also, Tesla has a much broader product range with more models of cars on their platform. A private network with an expanded product line creates an entry deterrence effect, which allows Tesla to achieve scale more quickly (both more EVs and bigger charging network).
5.3. Management of Value Chains Versus Platforms

Platforms pose a major disruption to decades old management wisdom and necessitate a rethink of management strategies. Five key characteristics prompt this rethink:

1) Platform product utility is the combined utility of multiple sides, stand-alone products have stand-alone value.
2) In platforms, unlike in products, the supply and demand side can incur cost or generate revenue.
3) Products depreciate in value through use, platform products appreciate value through use.
4) Network effects typically scale better outside of the firm, meaning value creation happens outside the company by:
   ○ Valuing interactions in addition to assets.
   ○ Shifting emphasis from employees to external contractors, from internal experts to external crowds.
5) Competition can occur at multiple layers: between platforms, between complementors and between the platform itself and its complementors.
   ○ Competitive advantage is generated by seamless access more often than classical entry barriers.

First, platform products must not maximize the utility of a product but the utility of a platform. For example, Tesla’s platform perspective optimizes the utility for electric mobility through its offering. The product “car” is combined with the product “charging” to form the platform product of electric mobility. In contrast, OEMs optimized for the standalone “car” product produce a beautifully engineered car at minimized production costs but leave the user mostly alone to figure out the charging aspect of the product. However, from the perspective of the OEMs this can be a viable strategy. As outlined, in the long run in the specific case of EVs, the platform aspect will decrease in importance. Once the charging infrastructure is built out to a sufficient degree, the characteristics of the car will dominate (as we see today with petrol stations and internal combustion engine cars). As OEMs historically optimized the production of cars and their design, they could employ a waiting strategy until these capabilities become dominant also in the BEV market again. However, given the relative advantage of OEMs in producing cars, for Tesla it made a lot of sense to act as platform provider to deliver both the cars and the charging.

Second, another major shift between standalone products are their basic economics. For standalone and pipeline-like products, the product itself incurs costs and realizes profits. Ultimately, the production costs of the product need to be lower than the realized revenues. In platform products, both sides can incur costs and accumulate revenue. Google’s GSuite incurs cost but does not realize any revenue with most private customers because it is largely offered for free. In a standalone offering this would not be a successful product, however with platform products this strategy is viable as all sides can incur costs and accumulate revenue. Tesla’s strategy to include “free” charging into their platform product is a viable option in platform markets, however it is not a viable option in a linear value chain business. The same is true for standalone charging infrastructure providers. Try as they might to optimize their product and its delivery, it will never be a viable standalone option to offer only charging for free. Also note, that although platform products have a higher degree of freedom in generating revenue, in the end revenue needs to come from somewhere. If Tesla does not monetize the charging network (charging is largely offered for free), they have to make money on the car. And in this space, they will in the long run face the core competencies of the OEMs.
Third, standalone products depreciate in value through use, while platform products appreciate value through use. This characteristic is most pertinent for digital products, as their use is nonrival (a good is nonrival when its use by one does not decrease its usefulness to any other agent). Given their physical nature, cars and charging stations are not nonrival but to a certain extent the characteristic still applies. The more Tesla cars are used on the road, the better the charging network will become as the incentives to deploy Tesla charging increases. And, because the data from cars in use can be used to optimize charging network performance, there is a network effect at work.

That leads to the fourth major shift: Typically, network effects scale better outside of the firm. This means that essentially value creation happens outside the company (compared to internal value creation with product firms). Hence, platform organizations need to open up and curate the external ecosystem of partners instead of their internal value chain. EV manufacturers would engage the players mentioned in the section on installed base to contribute to the platform. Tesla, for example, as a currently low-margin and loss-occurring hardware manufacturer could franchise or outsource the “car-side” and focus on offering the software component that is the charging network. However, none of the players is actively pursuing that strategy. The OEMs are still managing their pipeline businesses while Tesla builds out the platform product with an integrated model playing on both sides. The relative inaction of the competition has not pressed Tesla into fully acting as an open platform.

Finally, platform products and value chain products also differ in the ways in which competition plays out. In pipeline business, actors mainly compete with other standalone products and the partners in the supply chain compete with similar firms in other supply chains. In platform business, competition can occur between platforms. The Tesla system competes with the systems of other OEMs. Further, complementors compete between each other on the same platform. A charging infrastructure provider in an open platform would compete for customers of the same platform. Today, this competition barely exists due to the relative lack of charging stations. Additionally, the platform itself can compete with its complementors. If Tesla were to open its platform to other charging providers, Tesla’s own supercharger network would compete with the other provider’s offerings.

5.4. Governing Openness

Platforms or multi-sided markets are defined by the interplay of various sides (the owner, the complementors, the users). It is essential to “establish governance mechanisms that appropriately bound participant behavior without excessively constraining the desired level of generativity” (Wareham et al. 2014, pp. 1195–1196). Governing openness promotes success, but how much do we want to rely on external contributors? What is needed to provide the incentives and structures to attract these?

In platform markets there are frequently strong arguments to choose openness. In these markets, firms essentially rely on the generativity of the outside network (Henfriddson and Bygstad, 2013). In plain language, individual apps are not essential, but millions of individual apps are critical. To generate such a variety of offerings, firms need to rely on an open network of partners to supply this. Additionally, the advantage of an open strategy is that the firm holds the options for success but outsources the risk of failure. If a developer decides to develop an application for the firm’s platform, it has options toward the success (if it will be a successful application, it makes the platform more attractive), while in the case of failure, the developer bears the vast majority of the costs.

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21 At the current stage of the market it is even questionable if OEMs have a platform system to compete with Tesla as they typically only cover the ‘car-side’ of the platform.
The power of openness has been impressively shown by the build-out of the Android ecosystem, the MySpace versus Facebook case, and the opening of Apple. The radical openness of Android allowed Google to overcome a late start when first Microsoft’s and then Apple’s ecosystem had threatened to dominate the smartphone market (Pon et al., 2014; West and Gallagher, 2006). Facebook’s dominance over MySpace only started when Facebook opened to an external ecosystem of partners in 2007 (e.g., Zynga’s Farmville attracted many users). Also, Apple got really successful after opening up compared to their rigorous closeness in the 1980s and 1990s:

“Steve Jobs failed miserably at managing openness at Apple in the 1980s. He charged developers for toolkits – inhibiting the very software producers he should have wanted on Apple’s platform. The result was that Apple struggled to create a robust platform connecting Apple customers and software producers. For years Apple’s market penetration hung in the single digits. Apple has since figured out this balance, of course, by opening the iOS platforms to app developers. By contrast, Bill Gates opened Windows to both software and hardware developers, making Windows the dominant desktop platform by virtue of its superior ability to connect software and hardware producers with consumers” (Van Alstyne, Parker and Choudary, 2016).

However, the story can also be told in terms of the potential negative effects of openness:

“Opening up one’s technology is not without costs—a lesson taught vividly by the case of IBM PC. In the late 1970s, the major personal computer manufacturers such as Apple and Atari used proprietary (closed) architectures, meaning that components produced for different systems were not compatible. When IBM entered the market with the PC, it utilized an open architecture, such that anyone could make “IBM-compatible” computers—effectively opening its architecture technology. This strategy greatly stimulated component suppliers to develop products for the PC (and PC-compatible computers), and IBM quickly became the market leader. However, once the PC proved successful, competitors soon flooded the market with PC-compatible computers, and IBM’s market share dwindled to 5% before it sold the whole PC business to Lenovo in 2005. In fact, IBM made unsuccessful attempts to regain control of the architecture, but could not turn the tide” (Hu, Hu and Yang, 2016, p. 133).

Yet, there are also examples of too much openness:

“Google learned this lesson when Amazon and Samsung fragmented (‘forked’ in tech lingo) the open Android platform to create their own open-source versions. Google Android quickly lost market share to the new versions. Reacting quickly, Google regained control of the Android system by restricting access to difficult-to-replicate services such as mapping and by shifting important application programming interfaces (APIs) to the proprietary Google Play Store. Android’s story demonstrates that platform openness is one of the key managerial decisions that can determine platform success or failure” (Van Alstyne, Parker & Choudary, 2016, p. 3).

These examples of openness decisions illustrate vividly the delicate management decisions that need to be addressed. Openness needs to be managed and controlled to avoid negative effects. For example, the quality of the platform offerings need to be managed. AirBnB has an interest to provide good quality listings, hosts, and guests. Uber has an interest to offer clean cars, punctual rides, and friendly drivers. And EV-producers have an interest that the offered charging stations are functional, users have adequate
payment options, and don't have to wait in lines for charging. Moreover, the adequate reward of the complementors needs to be managed and poses another delicate management task. For example,

“Back in 2000, several automakers including Daimler-Chrysler, Ford, GM, Nissan and others invested in Covisint, an online marketplace intended to match buyers and suppliers of auto parts. Unfortunately, Covisint’s ownership structure and auction format heavily favored auto companies (the consumers on the platform) while forcing suppliers into fierce price competition, leaving them with little or no residual value. As a result, parts suppliers left the platform and the market never became sustainably profitable. In 2004, the residual assets were sold off for a mere $7 million, a tiny fraction of the $500 million auto manufacturers had invested” (Van Alstyne, Parker and Choudary, 2016, p. 4).

In the case of EVs, the question of openness is of central importance mainly because of the high investment costs and the benefits of local information that is needed to build the charging network. In an open system, the investment costs (and risks) could be shared among many players and local knowledge could be harnessed decentrally.

Again, the players in the market employed varying strategies of empowering openness in their strategies to deploy EVs. The incumbent OEMs followed a rather open approach to agree upon and set open standards for the complement and invited other players to invest into the charging infrastructure. Both around the CHAdeMO and the Type 2 standard potent industry consortia formed. In contrast, Tesla followed a closed approach by developing non-compatible charging infrastructure (especially on the software side) and decided to build out the complementing almost completely on its own (with the exception of the Destination Charging program for Level 1 charging). However, Tesla did not follow a strictly closed approach. Tesla also opened up patents to invite complementors to build on this (as already previously discussed in the section on signalling). Despite the use of some forms of openness strategies, neither the incumbent OEMs nor Tesla were able to fully leverage the advantages of an open strategy.

Although Tesla showed impressive progress in deploying fast charging infrastructure in many countries and through their closed approach can ensure comparably extremely high levels of quality for their complement, Tesla lacks the generativity of a bigger ecosystem. As a result, scaling becomes difficult. In 2017, with the announcement of the Model 3 and 400,000 pre-orders for this vehicle, an analysis by UBS found that in order to ensure similar coverage as the existing network, it would need to add around 7,500 superchargers to match the increased demand of the Model 3. To achieve a similar coverage to existing gas stations, an additional 30,000 superchargers would need to be added to their network (DeBord, 2017). Tesla needs to make money on one side at least, the car or the charging infrastructure. This dilemma comes with critical questions:

- On which side to make money in the long-run? Thinking of this as a finite-horizon game (eventually the network will become competitive), do you make high margins on side 1 (EV), in which case (like Apple) you keep it closed? Or do you make money on side 2 (charging), in which case you open the system? Should Tesla keep losing money making cars, or should they change their business model?
- How long do you keep the network proprietary (as a function of anticipating entry by new competitors)?
- How rapidly do you deploy the supercharger network (which goes hand in hand with how many cars you make and which kind of cars)?
A possible way forward could be counterintuitive to classical strategy point of view: Become more open on the car side by opening patents (and thus become a partially open platform architecture). This could help to scale and decrease costs in the entire supply chain and consequently build the installed base of cars. As Tesla owns the proprietary complement (the charging infrastructure), they could retain sufficient control. Moreover, Tesla could use the lead in charging network to delay or deter entry of competitors. Tesla could continue to control very critical aspects of the system, such as route planning, and become a complement in adjacent platform markets such as energy, stationary trade, or introduce reservation systems.

The OEMs played a different game. As they are typically profitable in producing cars, their strategy was to push very open and standardized systems (one defined plug). In other words, OEMs chose to invite as many players as possible to build out the complementing charging infrastructure to leverage the generativity of a broader ecosystem. However, as this open system was not actively managed, it ran into several strategic and operational problems:

- The lack of coordination between the two sides of the platform (car sales and deployment of charging infrastructure at the right place at the right time) exacerbated the complexity and fragmentation of the system.\textsuperscript{22} This is further complicated with delayed feedback (building charging infrastructure takes time from the initial intent and planning to opening).
- The extremely open architecture led to extremely high variety in charging systems (access, billing, software protocols, etc.) and a fragmented market.
- The quality of the complements is not sufficient. This includes software features such as live availability data which is the basis for route planning, decreasing range anxiety or a reservation system.
- The option space for platform architecture products was not fully exploited. For instance participants did not employ the following coordination strategies:
  - Subsidizing
  - Signalling
  - Leverage of common installed based
  - Exclusivity agreements
  - Bundling
  - Product quality and range

6. Outlining Future Strategic Directions

In this chapter, we aim to give an overview of strategic decisions actors are currently faced with and to apply the platforms literature to frame the trade-offs underlying these decisions.

\textsuperscript{22}This lack of coordination between the sides resulted in what an industry analyst describes as state of the industry “...uncoordinated development with no reference to existing facilities, and accessed by proprietary means of access and payment, creating yet another layer of complexity and fragmentation on what is already a deeply fragmented system” (Miles, 2019).
6.1. Finding an Answer for Both Sides of the Market

One of the fundamental premises of platform markets is that both sides of the market must grow in parallel. Investments in one side of the market will prove to be wasted under a lack of robust growth in the second side. The BEV industry has not demonstrated success in effectively and efficiently coordinating both sides of the market. On the one hand, both automobile makers and independent charging infrastructure providers have primarily focused on their respective sides of the market. On the other hand, while Tesla has managed both sides until now, its limitations in perfecting manufacturing efficiency and supply chains may cause challenges and capital constraints in the long run. For participants to be successful in this platform market, they must effectively harness the strategic options multi-sided markets offer. What are some things they could do better?

**Coordinate through pricing:** First, the players in the market can make use of coordinated pricing between OEMs and independent charging infrastructure providers (EVgo, Charge Now, Electrify America, utilities). Without coordination, the charging infrastructure side tries to run a profitable stand-alone network and suffers from low utilization rates, leading to slower expansion of the network and, in turn, to slower adoption of BEVs due to the lack of charging infrastructure availability for customers. This deadlock could be overcome if, for example, OEMs factor an amount of “charging credit” into the selling price of the car to provide a certain subsidy to the charging side.

**Coordinate the software level:** Second, the market coordination also needs to happen on the software level. Based on consumer preferences, the machines (car and charging infrastructure) should be able to communicate to optimize the overall system. This starts with simple real-time information about availability, future availability (how long will the currently charging cars still take), pricing for preferential access or charging speed, and could go into route optimization based on charging needs. For that to happen, either a technological standard will emerge, or it will be likely that this market-coordination service will be offered by a platform that tries to aggregate data from both sides and coordinate the two sides.

6.2. How OEMs Will Deal with Tesla’s Lead in Supercharger Stations

As laid out before, all players in the game need to actively play the platform architecture of BEVs in order to be successful. Being a second mover, for OEMs one of the critical questions will be how to handle the lead of Tesla for the complementary product. Although Tesla has arguably a lead on both sides of the market, it is comparably easier for the OEMs to catch up on the hardware (car) side.

**Building their own:** While building the complementary on their own offers the advantages of optimizing the interfaces, arguably faster decisions and less coordination across organizations, it requires higher investments and comes with high uncertainty of utilization and access for customers. OEMs could very actively target Tesla’s current white spots both in terms of car sales and infrastructure deployment. However, given the lead of Tesla’s superchargers across highways, it mostly means building up redundant infrastructure.

**Partner with other OEMs:** Partnering up with other OEMs and trying to jointly challenge Tesla comes with the advantage of shared investments and a much larger installed base on the car side. This reduces uncertainty about complement utilization. However, it requires collaboration
between competitors and potentially lengthy coordination. A Joint Industry Computerized Reservation System (JICRS) scenario is likely to develop. Additionally, in both scenarios, OEMs must convince their stakeholders that they are moving into the business of charging.

**Partner with Tesla and pay for the access to the network:** A third option for OEMs would be to pay for the access to Tesla’s network. This would immediately open a broad installed base of the complement to their own customers. For Tesla, the advantage is that it would amplify Tesla’s ability to monetize a high-cost infrastructure and expand its market reach to customers of competitors’ products.

### 6.3. Tesla Switches the Game, But When?

Assuming that Tesla needs to make consistent profits eventually, simply said there are two strategic options Tesla can play. Currently, Tesla aims to make profits by selling cars and mostly subsidizing the charging side of the platform. However, Tesla could turn this around and try to largely monetize the charging network and subsidize the car-side of the platform. There are several factors that make such a switch increasingly likely. First, while moving from a premium manufacturer with low unit outputs to a mass manufacturer with high unit outputs, generally margins shrink and competition from existing OEMs increases. Second, many more OEMs (which are likely have better optimized productions) seem to move into the market with new BEV models and increasing competition and accelerating price pressure. Third, Tesla’s charging network is the most extensive and comprehensive in many markets and Tesla is in the unique position to control two-sides of the platform, which likely gives them a know-how advantage. The biggest question for Tesla is how defensible is their charging network when opening up?

Local network effects and consumer heterogeneity help to defend the network in the short run. However, in the long run, these will become less important as mergers on the side of charging network providers will happen and charging becomes more and more a commodity making the network hard to defend. Additionally, the public supercharging network “competes” with increasing battery capacity and the option for home-charging, decreasing the likely utilization levels in the long-run. Customers who have high-quality home charging are likely to have limited and highly unpredictable need for a public supercharging network. In light of this, charging station providers might need to rethink monetization strategies, perhaps switching from the current per-unit pricing model to a two-part tariff pricing scheme where customers pay for both membership (or right to access the network when the need arises) and usage.

New technological developments, such as ever-increasing charging performance, expose Tesla’s installed base to be overtaken by new technology generations--on both sides of the market! Also, history teaches that, in many cases, only for the second owner or after significant write-offs does infrastructure become profitable. For example, the Eurotunnel that connects France and Great Britain under the English Channel was unprofitable for more than a decade and became profitable only after a significant debt write-off of £3,400 million. The biggest opportunity to defend the network in the long run would be the failure of competition to effectively coordinate cars and infrastructure--a scenario that is not uncommon in platform markets (e.g. in the SABRE case, but also in the case of CHAdeMO the challenges of coordination become apparent).
6.4. Effectively Work Scarce Capacity and Fragmented Markets

Currently, fast charging infrastructure is a scarce good both in general availability (density of the network) as well as in specific (comparably long waiting times once it is blocked). Surprisingly, capacity markets, which typically emerge in scarce industries, have been left out so far. Hence, it is likely that this market will still emerge, as long as it remains a scarce good. In the easiest form, this scarcity can be for example exploited through a reservation system, for example, that provides the security of having a charging spot when needed through paying a fee or premium. Additionally, preferences of slower and faster charging needs can be taken into account.

Additionally, the currently fragmented market of charging infrastructure providers with many different providers and access, pricing and billing systems is likely to undergo a consolidation comparable to aviation alliances, which leveraged joint routing, preferential access and pricing to members, as well as bundling options.

6.5. Create and Make Use of Good Quality and Dense Data

As already outlined above, data on both sides of the market could substantially help to coordinate the sides of the marketplace. It is surprising that for the most part, good quality and dense real-time data about supply and demand for charging have not been utilized (again, with Tesla being the exception in delivering real-time information about charger locations and availability to customers). Taking the learnings from other platform architecture markets, it is likely that in the short-term mid-level data platforms will emerge that offer services such as real-time information about charging station availability and reservation options. These platforms solely work the data layer across providers of both sides and perform a critical coordinating role. The level of openness of both the hardware (car) and software (charging) providers to allow for “generativity” will define the speed and richness of this solution.

6.6. Investors Need to Accept the “Platform Game”

In order to win in the platform game, investors need to start accepting the rules. Building and coordinating multiple sides of a market typically requires high upfront investments over an extended period of time primarily because demand side economies of scale are slower to achieve and harder to predict. For many years after its IPO, Amazon reported quarterly losses as it invested into a multi-sided marketplace. But in 2017--over 14 years after its IPO--they reported a profit that exceeded the cumulative profits of all 58 previous quarters (Griswold and Karaian, 2018). Much to the surprise of Wall Street, Jeff Bezos was able to invest over long period of losses and build out a multi-sided platform. Elon Musk is similarly succeeding in convincing public investors to repeat quarterly losses in favor of growing and building a platform business (although that is rarely Tesla’s communicated strategy).

However, many investors are not willing to support such investment in, or their analytical tools are not designed for, a world of multi-sided platforms. Surprisingly, the vast majority of comments from Wall Street analysts covering Tesla do not cover its multi-sided product architecture. That fact makes it increasingly difficult for public companies to switch from a pipeline business into a market where a company invests in two or multiple sides simultaneously. On the contrary, venture capital investors have been much better in detecting and understanding the dynamics of multi-sided markets and investments.
in complementary products. The relative lack of venture capital into the complementary product indicates that they do not expect superior profits down the road.

6.7. Productivity Gains in Building Charging Network

An open question is, if in building out the complementing charging network, productivity gains can be realized, and economies of scope and scale are existent? If that is the case, Tesla’s network is more likely to be defensible, whereas if it is not, the emergence of a mid-market platform coordinating the fragmented market of many suppliers is more likely.

On the one side, it is likely that productivity gains and economies of scale can be realized from purchasing equipment and energy in bulk as well as from learning effects in building out the network. On the other side, there are strong arguments that significant productivity gains can be realized in building out the network. By definition, it is a fragmented business, entails significant labor costs, and deals with a fragmented purchasing market for energy (e.g., often local energy providers). Site specific differences result in recurring planning costs, and most importantly, the “easiest” locations are typically built first, which increases the likelihood that the next charging station will cost more. However, this argument also favors the early mover and, for Tesla, increases its chances to create a defensible network. Taken together, it is unlikely to see significant productivity gains in building out the charging network, which decreases its defensibility.

6.8. Ultimately: Prepare for a "Joint Industry Wide Supercharging Network"

Despite likely being defensible in the short run, it is very unlikely that proprietary charging networks are defensible in the long run and the likely low profits make this complement rather unattractive to defend. Hence, sooner rather than later, the industry will move toward a joint supercharging network. However, this development by no means can be taken for granted. In the 1970s, driven by technological innovations and deregulation efforts, the American airline industry started several attempts to jointly develop a standard passenger reservation system that would allow travel agents to book airline seats directly with multiple airlines (reducing the process from about 90 minutes to a few seconds). The largest attempt was the Joint Industry Computerized Reservation System (JICRS), that was evaluated as technologically feasible and economically attractive to all participating airlines (Copeland and McKenny, 1988). Nonetheless, the partnering airlines could not agree on the mechanisms of cost sharing and voting rights in the consortium (Copeland and McKenny, 1988). Ultimately, several airlines developed their proprietary systems and fought a costly battle for market dominance (Copeland and McKenny, 1988).

A joint network poses continuous coordination challenges on its network members. It is likely that there will be technological advances in charging and battery technology for the coming years. In order to be compatible with the network, industry-wide standards become significant. Overall, policy interventions are likely.
6.9. What Should Policy Makers Do, If Anything, to Promote Competition?

The current state of the market sees potentially two parallel platform markets compete. On the one side Tesla builds its proprietary fast-charging network and on the other side other players build another more open charging network that in itself may be fragmented into many smaller networks. Policy makers can either decide to let the market’s competitive processes define the winner or decide to take actively promote competition. In general, a platform market is associated with market power through its multi-sided nature, economies of scale, data-driven economies of scope, and the virtuous cycle of network effects. However, market power that is gained through an efficient competitive process is generally good news because it implies efficiency in the production process and high quality products and services. When a dominant position is associated with maximization of efficiency in production and value creation, it should be welcomed (see Parker et al. 2020).

However, letting market participants fight it out can be a capital intensive, long, inefficient and wasteful process. A recent example is the standard war between Sony’s Blu-ray and Toshiba’s HD-DVD. The competition started in the early 2000s and continued until 2008 when Toshiba announced to cease development of the HD-DVD (den Uijl & de Vries, 2013). In order to win the market, both players and their respective consortia spent billions of dollars to subsidize their respective complement markets to tip the market in their favor (den Uijl & de Vries, 2013).

Policy makers may elect an altogether different set of actions in the market for BEVs. If the society wants to prevent a long and costly competition between various platforms, because the desirable outcome would be a faster transition to carbon-free transportation, policy makers should intervene. But instead of looking at traditional antitrust regulation, tools should focus on value creation before focusing on competition. On the charging network side, it is important to ensure that multihoming is possible between platforms. A first step to achieve this is to reduce the switching costs (the Open Charge Point Protocol is an important step for this) and ensure data portability. At the same time, this open standard should be encouraged where interoperability between different competing platforms is enforced (between Tesla’s charging network and other more open networks). Additionally, we already see that traditional (ex-post) antitrust intervention will be less effective in markets driven by network effects and policy makers need to combine it with a proper (ex-ante) regulatory framework (Parker et al., 2020).

7. Research Agenda

At a high level, we would argue that platforms and network effects are driving a fundamental restructuring of supply chains as firms learn to incorporate these market characteristics into their strategic and tactical plans. In this article, we laid out the perspective and insights one might gain from viewing the current state of the electric vehicle market from the platform lens and how such a view affects firm strategies as they seek to compete in the BEV market. Many other markets also share time and/or spatial, and/or product/company, and network effect characteristics. Further examination of these markets will, undoubtedly, contribute to the developing understanding of the platform economy.

Electricity: EVs are not just automobiles, but also can serve as mediators in electricity production, storage, and reuse (see Weiller & Pollitt (2016) for an overview). Zooming out and including the EVs and charging infrastructures’ possible role in the energy systems reveals additional platform architectures, again with important data layers (Parker, Tan, and Kazan 2019. The deployment of volatile energy resources (typical for many forms of renewable energy resources) is positively correlated with the need
for energy storage. This issue is currently not as apparent, as established power plants and flexible demand side energy sources can balance the fluctuations. However, in the long run the electricity storage capacity of EV’s batteries could be an important part of this system. And the story of the platform architecture repeats--the deployment of more volatile energy resources will depend on the deployment of storage systems. Many of the issues, but also opportunities to actively manage this platform, similarly arise.

**Internet of Things (IoT):** The vast majority of IoT applications involve strong same-side and cross-side network effects. Given that it is beneficial for a user to connect and manage a refrigerator by a mobile application, it would be increasingly beneficial if the user could connect with other home appliances or broader smart home applications. At the same time, it would be even more valuable when these devices connect to services outside of the home such as automatic refill of the milk that is about to run out. On the other side, the more appliances connect to one provider of refilling services the better their services presumably become. At the same time, connecting many milk bottles to the platform could improve refilling process. Naturally, we can continue on this road for quite a way and in the same manner for industrial IoT applications, but the mechanisms should be obvious.

**Smart Cities:** Although many of the IoT examples equally apply to Smart Cities, some additional domains with platform characteristics emerge. For example, many cities try to establish open data platforms, where urban data is more or less freely accessible in the hope to spur entrepreneurial activity in the city and innovative solutions. However, effective governance mechanisms that balance generativity and control in this context seem yet to be identified. Additionally, many possible connections and network effects can be possible, raising the question of what is the chicken and what is the egg? One example is the problem of finding parking in cities or matching available parking spaces with cars searching for parking. This could be solved by many different solutions: predictive models of smartphone data, sensors in parking lots, virtual reservation systems, sensors in cars, and many more. However, a solution is most likely to emerge when all vehicles in a city use the same system and the question of where to start remains.

**Supply Chains:** At a high level, all of the industries we have discussed in this monograph are examples of how supply chains can be reconfigured using platform resources. The traditional business architecture that evolved after the early industrial revolutions required firms to build large and stable production and distribution systems in order to enjoy economies of scale and achieve lower marginal costs. This architecture, which dominated businesses in the 20th century, typically involved supply chains comprising tens of thousands of thoroughly vetted business partners under long-term bespoke contracts, thereby achieving predictable supply and production. Yet, demand in most industries is volatile, fragmented, and not fully predictable, creating a messy demand-supply matching problem. Platforms take a different approach to this problem. Rather than have highly negotiated bespoke contracts, platforms use information technologies to enable lightweight, automated, and possibly short-lived, contracts, thereby building out a dynamic ecosystem with thousands or millions of business partners. Where relationships were once relatively stable, platforms offer the opportunity to reconfigure technology, assets, and partners more fluidly than in the past. Supply (or demand) components can be turned on and off as needed, making the overall system more responsive and optimized to current realities than a traditional batch optimized system with rigid long-term allocations.

Consider Toyota City in Japan. The constellation of firms that supply Toyota clustered near the firm over time and formed an interdependent system for product design, development, manufacturing, and logistics. The relationships tended to be fairly stable over time. By contrast, firms that work with the
SAP or Salesforce platforms can be attached to the system more quickly to provide solutions to a broader set of end customers using platform technology. A supply chain view provides a fundamental link to existing operations management practice and scholarship, and the increasing impact that platforms that harness network effects are having on firm operations.

**Final Observations**

In this article, we have analyzed the battery electric vehicle industry from a platform perspective. We have provided significant historical context for the BEV industry and have also provided a review of the platform literature. One of our major goals in undertaking this project is to call increased operations management research attention to platform markets. We believe that analyzing markets from a platform and network effects perspective will yield valuable insights about possible decision spaces and strategic directions for firms. Thus, we invite scholars to think about their research and see how they might productively incorporate a platform view.
### Acronyms and Definitions

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
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<tr>
<td>CCS</td>
<td>Combined Charging System</td>
</tr>
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<td>CDMA</td>
<td>Family of third generation mobile technology standards predominantly used in North America.</td>
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<td>CHAdeMO</td>
<td>CHArge de MOve - is the trade name of a quick charging method for battery electric vehicles</td>
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<tr>
<td>DCFC</td>
<td>Direct Current Fast Charging</td>
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<tr>
<td>EV</td>
<td>Electric Vehicle</td>
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<tr>
<td>EVC</td>
<td>Electrical Vehicle Company</td>
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<tr>
<td>GSM</td>
<td>Global System for Mobile Communications – a European telecommunications standard for second generation (2G) cellular networks.</td>
</tr>
<tr>
<td>IB</td>
<td>Installed Base</td>
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<tr>
<td>JICRS</td>
<td>Joint Industry Computerized Reservation System</td>
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<tr>
<td>MSP</td>
<td>Multi-sided platform. The literature uses the terms &quot;platforms,&quot; &quot;multi-sided platforms,&quot; and &quot;two-sided markets&quot; interchangeably.</td>
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<tr>
<td>OCPP</td>
<td>Open Charge Point Protocol</td>
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<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer – in this paper equivalent to car manufacturers</td>
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<tr>
<td>OM</td>
<td>Operations Management</td>
</tr>
<tr>
<td>SABRE</td>
<td>Semi-automated Business Research Environment – Sabre aggregates airlines, hotels, online and offline travel agents and travel buyers</td>
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</table>
7. Bibliography


Woodyard, C. (2015). Tesla Pulls Out Stops with Sleek New SUV: At 0 to 60 mph in 3.2 Seconds, the Model X is World’s Fastest SUV. *USA Today*. 30 Sep 2015.


