APPENDIX 3: LOOKING AHEAD: THE EMERGENCE OF AN ELECTRIC VEHICLE INDUSTRY

One final application of our framework comes from our fieldwork. In addition to considering why value has not migrated in automobiles, we also examined expectations of how value distribution would be affected by the emergence of an electric vehicle (EV) industry that is (slowly) displacing the current dominant design, which relies on gasoline-powered internal combustion engines (ICE). Interestingly, this pending transition is already drawing predictions of a dramatic shift to a horizontal structure and full modularity, not unlike those that were widely floated during the 1990s. Figures A1a and A1b reveal how a prominent consulting firm sees this future industry architecture.

*** Insert Figures A1a and A1b about here ***

This section provides an illustration of our framework, as well as an opportunity to ensure that it is useful to practitioners and social scientists hoping to make predictions. Methodologically, we feel that putting an inductive theory through this test helps us refine it – and provides an opportunity to apply what we induced to make directional predictions.

To start, we note that the EV does entail substantial potential change for the sector. In particular, this is a new and different segment, with high potential growth, and with a very small current scale; and its technologies also may challenge the ability of the OEM to keep control. But, for all the talk of transformation, what exactly is the potential change here? Here we offer our own views, informed by our framework, looking at both structural forces and mechanisms for strategic control. Note that we reorder the sequence here, reversing the order in the main text, i.e., we cover the structural forces first and then the mechanisms of strategic control, since prediction starts with an understanding of structure, upon which strategic interaction rests.

**Technological clockspeed and dominant design.** An electric vehicle replaces the ICE plus manual/automatic transmission with completely new technologies, thus offering the first significant departure from an automobile’s dominant design since the late 1920s. Furthermore, the pace of technical change in many of these technologies is likely to be quicker than in the recent ICE-dominated past. Indeed, there may be a quickened pace for innovation overall due to competition among incumbent and novel technologies that is likely to produce a “last gasp” spurt of ICE-related advances.

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1 This appendix applies the framework from Jacobides, MacDuffie, and Tae (2013) to the emergence of the electric vehicle industry. That paper is being distributed separately.

2 Of course, electric propulsion was one of the technical options that lost out to ICEs at that time, the close friendship of Henry Ford and Thomas Edison notwithstanding (Rubenstein, 2001).
An electric vehicle’s product architecture can differ substantially from the current dominant design. Electric motors are highly efficient, with precisely controlled acceleration; variable gears are not needed, since, when properly designed, these motors can generate high torque from full rest. They can be combined with regenerative braking, in which the energy generated during slowing or stopping can be used to charge the battery; this reduces wear, improves efficiency, and requires the redesign of brake systems. Motors can be distributed at the periphery of the vehicle, one for each wheel. In combination, these changes can free up tremendous space in the engine compartment and allow new physical configurations for existing components. However, the battery that stores and allocates electricity to the drive train is currently large and heavy, taking up space typically allocated to rear-seat passengers or storage.

Thus, on the whole, these changes represent the opposite of the trend with computers, in which increasingly small form factors (e.g. for laptops, netbooks, tablets, and phones) force increasingly integrated designs. In battery-only electric vehicles, more open space under the hood will invite design flexibility in both components and architecture, even as locating battery packs efficiently (at least at their current size) may impose new constraints elsewhere in the vehicle.

In this redesigned architecture, electronic controls embedded in software can much more fully replace physical controls, accelerating a trend already underway. Physical components are thus likely to be more modular, with lower interdependence across components and less complex interface requirements, and software providing much of the integration of vehicle functions. Noise, vibration, and harshness (NVH), which are particularly difficult to control in the current dominant design because they emerge from difficult-to-predict systemic interactions, can be much reduced. That said, an electric vehicle is still a power/energy system, in Whitney’s (1996) sense, and as such, its architecture must still mitigate problems of heat and vibration while dealing with new issues associated with higher-voltage electrical currents. Furthermore, this dramatically different drive train must still be integrated into all other vehicle subsystems, so the product as a whole is still complex and will require substantial system integration.

Overall, the technological break from the dominant ICE design could trigger a period of innovation and instability in which alternative designs compete, favoring value migration to any specialized supplier that could control a bottleneck resource, e.g. rare earths such as lanthanum (not so rare, as 10lb/4.5kg is used in each Toyota Prius nickel-metal hydride battery) and neodymium (crucial for helping shrink the size of magnets in electric motors). A breakthrough in battery technology where the IP could be protected by the lead firm developing the innovation could certainly shift value dramatically for as long as that firm enjoyed a monopoly on the battery or was able to establish a semi-proprietary standard that was adopted at a platform throughout the ecosystem (Cusumano, 2010). Under these conditions of technical uncertainty, industry clockspeed is likely to increase, while the opening up of the dominant design to possibilities of radical architectural innovation offers prospects for changes in industry architecture as well. However, the influence of other structural factors may moderate, perhaps heavily, this technology-based potential for change, as we now explain.
**Scale and growth.** We can anticipate that the growth potential of the EV market will attract excitement from potential investors and venture capital – the first time in several decades that this has been true for the auto sector. Indeed, we have already seen flurries of investor interest and the creation of new OEMs (such as Tesla and Fiskar) and suppliers (such as battery makers LG Chem and Envia). These new entrants can potentially disrupt the sector, leading to value migration between OEMs and possibly even shifting power away from them. However, this outcome hinges on how, and whether, that growth potential is realized.

An obvious but powerful fact is that electric vehicles will sell at low volumes for a very long time, absent either a major disruptive technological change or massive public policy actions to subsidize their sales and the recharging infrastructure, both private and public, that will be needed. Already, multiple variants of (partially or wholly) electric vehicle design coexist (fully battery-powered electric (BEV); electric-gasoline ICE hybrid (HEV); plug-in hybrid (PHEV); electric-assisted ICE), along with other fuel-saving and emission-reducing technologies, such as clean diesel, which provide an alternate path to meeting regulatory standards and consumer demand. At such low volumes, current OEMs and potential new entrants face daunting economic challenges in an industry where economies of scale have been so dominant. While this might make industry standards and relying on “modular markets” desirable, it also makes the economics of production more challenging for potential OEMs.

At the outset, the prospect of low volume and slow growth discourages investment and encourages conservatism in design. An example is the Chevrolet Volt, which uses an ICE purely for recharging the battery when necessary, a different approach to dual drive train design than that of Toyota’s or Honda’s HEVs. The initial Volt design deploys the same four-cylinder engine designed for the Chevrolet Cruze, which is far heavier and more powerful than what is required for the battery recharging task, and thus may affect vehicle attributes such as fuel efficiency and handling. The reason is simple: GM didn’t want to design a customized ICE just for the Volt, given the expected low volumes. By the time GM designs a new combination of ICE and electric motor for the next generation of the Volt, consumer impressions of the Volt’s unique design will be formed, for better or worse.

More significantly, given the auto industry’s history of OEMs achieving sufficiently high volume of proprietary-design components produced (or purchased) for its own models to achieve economies of scale, it raises the question of whether OEMs will be willing to procure more components designed to an industry standard, rather than a firm-proprietary one, for electric vehicles. The desire to achieve scale economies to take advantage of a rapidly expanding market (should that materialize) might very well push OEMs to consider industry standards for certain EV-related components in order to pool demand and drive down costs. However, this is by no means the obvious or even likely outcome, as a closer look at the implications for industry architecture vis-à-vis OEM-supplier relations will reveal.

Meanwhile, what of new entrants into OEM ranks for electric vehicles? The most prominent among these, Fisker and Tesla, are both quite vertically integrated, overseeing the entire process from R&D and design through manufacturing and distribution (and both getting U.S.
government subsidies to support their manufacturing operations, established in closed OEM assembly plants). These firms certainly represent something new – there has not been a new U.S. OEM since the short-lived, ill-fated firm making the DeLorean sports car. One prediction we heard in our interviews is that if either Fisker or Tesla is successful, it is likely to scale via acquisition by an existing OEM, rather than through organic growth. The fact that Toyota has already taken a substantial stake in Tesla, and that Fisker is struggling now to raise additional funds, suggests that this is a likely outcome.3

The structure of supplier agreements and the openness of standards. EVs pose economic and technological challenges with respect to the capabilities of OEMs vs. suppliers. Battery design requires chemical engineering expertise not typically found in the auto industry, and greater electronics expertise is needed to design the control systems for BEV and HEV. Changing to new drive trains may accelerate the use of alternative materials (from steel to composites), allowing lighter-weight vehicles that will consume less energy while also being sufficiently protective during impact from an accident. It is an open question whether these new areas of specialized expertise will be dominated by new suppliers (or existing suppliers with proximate expertise and absorptive capacity) or whether OEMs will continue with their pattern of making large R&D investments to master all technologies that a supplier might propose to use, in order to retain control over the overall product architecture.

So far, the early evidence suggests the latter. An industry analyst told us that multiple OEMs are deciding that they need to be “chemically competent” and are rapidly hiring chemical engineers so they can evaluate alternate battery designs and different battery suppliers. From a learning perspective, the integration challenge for OEMs of bringing new chemical and electronics expertise together with established knowledge around electromechanics, metallurgy, and styling is large and will require time, justifying this investment. Furthermore, a Canadian government official told us, “We see signs that OEMs are thinking of bringing battery-pack manufacturing into their own plants, since they believe they can do it better and

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3 Less known is U.S. startup Coda, which will sell a single EV model, assembled in California based on a body/frame and components produced by a partner firm in China and a battery from Korea. Coda is also establishing its own dealer network (calling them “experience centers”), with five so far in California. Founded by a former investment banker and attracting funding from many prominent investors, Coda’s progress has been well behind its predictions; according to a recent profile, “The company has scant revenues, has no profits, is about two years behind its original production schedule, and is working through its third CEO. So far Coda has sold fewer than 500 cars, whose design looks like a Chinese version of a 1990s Ford Escort” (Dumaine, 2012). Safety certification has been a particular challenge; in August 2012, Coda issued a recall on seventy-eight of its 2012 electric sedans because the side curtain airbags may not deploy, according to the National Highway Traffic Safety Administration.

An industry analyst whom we interviewed pointed out that Coda’s model is closest to the computer industry, with a U.S.-originated design, components purchased from all over the world, subassembly manufacturing in low-labor-cost settings, final assembly in the U.S. to allow certification as “U.S.-manufactured”, and extensive marketing to appeal to different user needs and wants (the product is only suitable for short-range commutes before needing a recharge, like most current BEV designs). He also said, “It is the most boring ugly car I’ve ever seen – who would want to pay $50,000 for that?” This demonstrates that a perennial challenge for new-entrant OEMs in EVs will be to meet the high expectations of consumers for styling, driveability, comfort, etc. while also winning them over to new technologies and a new distribution model.
cheaper” than these new suppliers who are early in the learning curve of how to be a high-productivity, high-quality manufacturer.

Low anticipated volumes for electric vehicles and the unfamiliarity of battery technologies make it unlikely that OEMs will vertically integrate battery design (even if they were to take over battery manufacturing). Joint venture arrangements are a possibility, although these might occur more naturally between firms with electronic and chemical engineering expertise rather than between OEMs and battery suppliers. Still, even if EV batteries continue to be designed and produced by specialized suppliers, we anticipate that OEMs will make sure they stay in a strong bargaining position vis-à-vis suppliers. As this would represent an extension of the current industry architecture into this new segment, we now explore the various ways in which OEMs will seek, we predict, to maintain their dominance over suppliers.

As suggested by the discussion above, technological and economic factors could encourage the adoption of industry-level standards for key electric vehicle components. Nevertheless, we see two primary reasons to doubt that industry standards will be forthcoming.

First, the overtures of A Better Place (see Vignette E) to gain industry support for a standardized battery, in support of its innovative battery-leasing-and-speedy-exchange business model, fell completely flat. OEMs brought technical arguments for why any standardized battery would not be sufficient to cover the range of vehicle types/sizes and drive train variants they were contemplating, but were probably also reacting negatively to a proposal that would put both technical parameters and an important source of economic value outside of their direct control. The prognosis for industry standards in other technologies, such as electric motors, is not yet clear, but extant examples give little reason to expect such standards to be forthcoming.\footnote{One relevant non-EV example is the fuel-injection technology developed first for diesel engines (and now being adapted to gasoline engines) by Bosch. After a brief and intense competition between two alternate designs, Bosch’s more mechanical design has become dominant due to quality and cost advantages over the alternate Delphi design, which relies more on electronics. (Note that both designs were acquired from smaller suppliers rather than being originated by these mega-suppliers; and that both designs require highly precise manufacturing in a clean-room environment.) Bosch’s design is deliberately specified to work in a wide variety of OEM vehicles without physical modification; only software modification to the engine management system is required. Thus Bosch has, for the moment at least, established an industry standard for a component of high economic value (at a purchased cost of roughly $1000 per vehicle). However, with OEM encouragement, two strong competitors – Siemens and Denso – are competing with Bosch for contracts, based on comparable designs. We predict that OEMs will push these three suppliers, once they are all proven capable with this technology, to develop OEM-specific variants. Under this pressure, whether Bosch will be able to maintain primary control of an industry-standard design remains to be seen, but history suggests that its prospects are not good.}

Second, OEMs are already developing relationships with multiple battery suppliers, partly in order to obtain multiple sources but also to get competitive bids. Under this familiar pattern, OEMs are likely to pressure battery suppliers to build to OEM-specific technical specifications and to share, if not initially then soon, technical IP that will support multiple design proposals from multiple suppliers. Some new-entrant battery suppliers (such as highly publicized A123, with technology from an MIT faculty member, subsidies from the federal government, and a
factory providing well-paying jobs in the Detroit area) have suffered from financial problems (lower-than-expected demand) and technical difficulties (manufacturing quality issues), which supports the inference that battery suppliers will struggle with many of the same pressures affecting all automotive suppliers. (In fact, due to its struggles, A123 was recently sold to a Chinese company.) The rumor that OEMs will pressure battery suppliers to allow battery-pack manufacturing to take place in OEM assembly plants is further evidence of forces for OEM-directed integration and control of this new technology.

In summary, while the break in the dominant design certainly creates an opportunity to establish industry-level standards (fully open standards are quite unthinkable in this context), the evidence so far suggests that the prevailing industry pattern will continue. Even where a supplier obtains a brief technical advantage, OEMs are likely to pursue their usual purchasing tactics for facilitating the diffusion of design innovations and competition among multiple suppliers on price, volume, and other contractual conditions. We therefore predict that the current hierarchical structure of supplier agreements and proprietary standards will persist for the EV segment.

**Identity and requirements of end users.** In terms of customer continuity, forces for change exist, but forces for conservation may prove to be very strong. We should recall that electric vehicles will require important infrastructure modifications to support vehicle recharging, from high-voltage lines at individual homes to recharging stations in parking lots and on city streets. Innovative ways of connecting vehicles to the electrical grid (“V2G”) are in development, whereby the capacity of vehicle batteries to store power could be used to sell power to the grid at peak times, and in turn to charge those batteries at lower rates during off-peak times. Smart grid technologies will ensure that the demand for battery recharging is distributed to low-usage nighttime hours. Finally, the battery-leasing business model pioneered by A Better Place, even though unsuccessful at persuading OEMs to adopt an industry standard, may shift the focus from a battery that an individual owns and is responsible for charging to a plan where the individual simply pays for the use of electricity in a battery owned by the leasing agency; this would limit the depreciation risk that buyers of BEVs now face, given uncertainty about the long-term viability of batteries.

The attention to charging reflects the reality that today’s batteries for electric vehicles have a limited range, making an answer to “range anxiety” the primary “user need” affecting EV purchase; this limitation doesn’t seem to be on its way out. Consumers, also deterred by high initial purchase cost and slow payback from savings on gasoline purchases, may be attracted by the appeal – and likely social status gains – of contributing to a greener environment, but this doesn’t sound quite revolutionary.

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5 While battery breakthroughs may be forthcoming, the science of battery power density has advanced only slowly over the past century, and there is little evidence to suggest an imminent change in that pace. According to one engineer we interviewed, “The limits to improving the power density of batteries can be expressed in quantum mechanics and are pretty daunting.” In this situation, the most important user requirement for electric vehicles may need to be addressed not within the product itself, but by external service providers who facilitate the necessary infrastructure support.
Will the switch to electric vehicles mean a change in the identity of users? Some have argued that governments may choose to subsidize the purchases of such vehicles to speed the reduction of emissions; however, it is almost certain that the ultimate purchasers of vehicles under such a plan would still be individual consumers, and not the governments themselves. Vehicles serving institutional purposes, such as buses and delivery trucks, are well suited to battery-only drive trains because centralized recharging controlled by a single entity is relatively easy to implement; these are likely to be purchased on a fleet basis by companies and governments, but this is also true with existing technology. So change will be limited.

Nor is it clear that electric propulsion technologies are likely to open up many new product categories. Electrification may well be applied to all vehicle types now powered by fossil fuels, but this is a substitution of energy source, not a new product. The way that the electrical grid is managed to support electric vehicles, among governments, businesses, and homeowners, is more likely to show innovative new categories of products and services than the vehicles themselves.

**Distribution channels.** New methods of distribution are somewhat more likely than new users, particularly since electric vehicles may lend themselves well to car-sharing services. Individuals may lease not only the electricity in the battery but the vehicle itself, paying for use by the hour or day. Thus the new business model of car-sharing pioneered by Zipcar (recently purchased by Avis), which emphasizes short-term rental for trips of limited length (e.g. errands for city dwellers), may dovetail well with the emergence of the EV segment, particularly if cities will provide not only a dedicated parking space for each car-share but also a recharging station. However, for primary individual owners of an electric vehicle, the current auto dealership model is likely to prevail. All in all, the forces of stability and continuity seem considerable.

**Regulatory requirements, quality certification, and legal liability.** While growth and scale, as well as the (slim, in our view) prospect of industry-level standards might make value migration somewhat plausible in the EV segment, forces for stasis on the regulatory and institutional front seem to be strong and will cast a long shadow.

The recent US government action concerning the Chevrolet Volt gives some indication of what will happen with regulation in an electric vehicle era. Following routine crash testing, a damaged Volt battery caught fire three weeks after the test, raising concerns about the risks to early responders (police, fire, and ambulance) after vehicle accidents. General Motors issued a voluntary recall, offering to refund purchasers of Volts who changed their minds, and a repair to enclose the battery in a metal case for all others. Comparisons made to the Nissan Leaf, another new electric vehicle, noted that the Leaf’s battery was fully enclosed in metal from the start. It is not difficult to imagine regulations that will specify such protections for electric vehicle batteries in the future. Workplace safety regulations are also applied to battery manufacturing facilities, given the risks of explosion. New regulations are also likely that require any vehicle that operates silently on electric power (including hybrids, before the ICE
starts up) to generate a noise that pedestrians can hear, for safety reasons. In short, regulatory oversight of electric vehicles is likely to be at least as stringent as it is for traditional vehicles.

Note also that it was General Motors, not the battery manufacturer LG Chem, that received the negative publicity about the Volt fire and undertook the remedies; this pattern is embedded in current laws and precedents and is unlikely to change, even if electric vehicle architecture is more modular and it is hypothetically easier to assign responsibility at the component level. The fundamental facts about automobiles as large, heavy, dangerous objects operating at high speed in public space won’t be changed by the disruptive technology of electric propulsion.

Given these structural conditions, which collectively seem to favor more structural continuity than change, what of the areas which are seen as strategically important by the participants in the sector? We now consider them both.

**Locus of differentiation.** For electric vehicles, given that the overall complexity of the product will still be high, with many different technologies to integrate, test, validate, and defend during the regulatory process, the OEM’s role as system integrator is highly likely to persist. As noted, there may be new relationships for OEMs to learn to manage, as with battery suppliers, whose capabilities were developed to serve the needs of other industries. With entire categories of components gone, the total number of suppliers may drop, particularly with the other forces for consolidation towards mega-suppliers already pushing in that direction. Since the complexity of the electric car is somewhat lower than that of ICE-powered vehicles, it is conceivable that the final customers (especially if these turn out to be municipalities or other sophisticated buyers) may be more involved in the design and integration process, but it is difficult to imagine any path to a viable electric vehicle that doesn’t run through a system integration process such as that now dominated by OEMs.

Another factor supportive of the OEM’s continued system integrator role is that OEMs will be managing a portfolio of alternate technologies for many years in the transition away from ICE drive trains, and may uniquely have the capability of handling the production, supply chain, and marketing/sales complexities of maintaining and modifying that mix over time.

**(Ir)replaceability.** While initial design experimentation will destabilize the dominant design and open up the industry to new suppliers and new bodies of expertise, it will not completely destabilize current roles/rules, since, as we note, the OEM role of system integrator will still be required. We see few paths allowing new entrants to move quickly into filling that role, and few incentives for even the most capable suppliers to integrate forward into full vehicle design, manufacturing, marketing, and oversight of distribution. OEMs are, in short, likely to prove irreplaceable as the guides to (and overseers of) an EV future.

Foreign OEMs seeking access to the U.S. (and other developed country markets) are the most likely new entrants, but they will face similar challenges in establishing a new approach to EVs. Interestingly, the Chinese battery manufacturer BYD (‘Build Your Dreams’) made headlines in recent years with its announcement that it would forward-integrate into designing and building electric vehicles, using its own proprietary battery design; it even attracted a
substantial investment from Warren Buffett. BYD acquired small Chinese domestic automakers and has focused initially on learning to build traditional ICE drive train vehicles. Its sole all-electric vehicle has sold only a few hundred units, primarily in fleet sales to regional governments. Although it initially announced ambitious plans to export both traditional and electric vehicles to the U.S. by the mid-2000s, it no longer claims any plans to do so, focusing for now on the Chinese domestic market. BYD is of interest as a new OEM arising from a different capability base, as an emerging-economy multinational firm, and for its ambitions to leapfrog into EV technology. However, its experience so far suggests the same long slow slog of capability improvement that Japanese and Korean OEMs before it have endured over a period measured in decades, not years. None of the trends reported above for EVs challenge this prognosis.

**Summary.** Overall, the impact of electric vehicle technology is likely to be greatest in breaking the current dominant design and moving product architecture towards more modularity, although industry-level standards for key components are already looking unlikely. Furthermore, regulatory requirements, quality certification and legal liability seem unlikely to change for EVs. This will help preserve the OEM’s system-integrator role and is likely to perpetuate complex dynamics of competition and cooperation between OEMs and suppliers, and among suppliers. While we may see new entrants into the OEM category with a pure EV focus, they are unlikely to come from the ranks of suppliers, may need extensive subsidization, and are likely to be acquired rather than surviving as independent firms, in part because they lack the full set of capabilities that OEMs in this industry have needed to meet societal/regulatory requirements and customer expectations/needs. Finally, new categories of services may arise in the provision of electricity, but electric propulsion doesn’t promise a whole new array of product offerings, and the purchasers and users of electric vehicles will still primarily be individual consumers. In our view, and consistent with our framework, electric vehicles’ impact on the environment and energy dependence will probably be greater than their impact on the automotive industry per se, which will be evolutionary rather than revolutionary.
APPENDIX REFERENCES


Figure A1a: Predictions of Horizontal Structure from Transition to Electric Vehicles

With the transformation to e-mobility there will be a significant change in the value chain of the automotive industry.

**Value Chains**
- Conventional Vehicle
- EV

**Key Points**
- Shift in profit allocation from assembly to information technology and components
- New “players” from different industries such as energy, IT, and electronics
- Change from one-to-one towards multi-multi structure
- Lower entry barriers


Figure A1b: Predictions of Modularization from Transition to Electric Vehicles

With “modularization” and “plug-and-play” concepts the role and power of suppliers in the industry will significantly shift.

- Definition of global standards enable “Modularization”
- Connectivity without calibration - “Plug-and-Play”
  1. Supply to two or more automakers
  2. Achieve economies of scale (similar to semiconductor industry)
  3. Mega-suppliers would become profitable, while automakers producing relatively small volumes of EVs would be less so