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Challenging the portfolio of powertrains perspective: time to choose sides

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Abstract

In this viewpoint paper we challenge the portfolio perspective that envisions a future in which a wide variety of automotive powertrains and fuels will co-exist. We argue that this perspective is driven by normative ideas and rhetoric and that it is more likely that a very limited set of rather similar technologies will survive as successors to the fossil fuel powered internal combustion engine. Economies of scale of core components and the necessary build-up of infrastructures will eventually give these a decisive lead over its competitors. Our perspective has two implications. First, the cars of the future are and will be competitors and hence there will be winners and losers. Second, policy should be targeted at the set of technologies that are most desirable from a societal and environmental perspective, rather than at the wide variety that is being developed today. Given the challenges of climate change and local air pollution, the electrification of the powertrain should be prioritized at the expense of alternative fuels such as natural gas and biofuels

Keywords: cars of the future, dominant design, innovation

1 Introduction

The car as we know it today can and will not last. Increasing concerns over GHG emissions, local air pollution, and dependence on imported oil force governments to impose ever more strict regulations on emissions and fuel efficiencies. Today's gasoline and diesel fuelled cars with combustion engines cannot meet these demands on the long run and an alternative design is therefore needed. The potential alternatives are plenty and they are being developed by both the incumbent firms in the automotive industry as well as by new entry firms. These developments are typical for a time of radical technological change: technological diversity increases and the number of firms offering them increases as well (Utterback 1994).

Researchers (Offer et al. 2011; Ogden et al. 2011), industry analysts (McKinsey 2010) and governmental foresight projects (European Expert Group on Future Transport Fuels 2011) often claim that the future of the car encompasses a portfolio of different fuels and powertrains. We refer to this idea as the *portfolio of powertrains perspective*. The basic reasoning behind this perspective is that all of the alternatives have their advantages and shortcomings and that none of them is able to satisfy all users by itself. Therefore, different users will select the technology that fits best with their mobility needs.

In this paper we challenge this perspective and we argue that it is naïve and that it thereby obscures the competition that will take place between the alternatives and their proponents. We build our counterarguments on historical insights that were found in historical studies of dynamics of innovation. On the basis of those insights one would rather expect that, after a so-called era of ferment, at most a small set of compatible and similar designs will come to dominate the industry. To be clear, we do not claim that it is altogether impossible for multiple types of cars to co-exist in a market. Moreover we do not have the ambition to predict what option will win in the end. Rather, we sketch a scenario in which the different cars of the future do compete for future dominance and in which it would be also be possible that sub-optimal solutions outcompete the most desirable ones. Current initiatives to support the introduction of specific options are therefore not 'innocent' and may hamper the development of other, more desirable options.

2 The portfolio perspective

In the development of the cars of the future, two alternative routes are explored. The first is to move away from the traditional fuels, gasoline and diesel, and switch to cleaner alternative fuels or electricity. The second is to re-invent the powertrain of the car in order to eliminate the combustion engine or at least to reduce its share in the propulsion of the vehicle. While the first entails radical change on the side of the fuelling/energizing infrastructure, the second entails radical innovation in the core technological component(s) of the car itself. Table 1 provides an overview of different fuel and powertrain options that might coexist according to the portfolio perspective. Altogether there are at least seven fuel options and six powertrain options and these are used in different combinations in the set of cars of the future. The number of combinations that make sense, both technologically and economically, ranges from 10 to 15, depending on the fuel types that are used in (plug-in) hybrid vehicles. When one also takes into account that there are multiple types of biofuels, natural gas (liquid and gaseous), and hydrogen (liquid and gaseous) and different means of delivering electricity to plug-in cars (normal, fast, swapping), the number of options is even bigger.

Table 1 The basic set of fuel and powertrain options that are being developed

Fuels	Gasoline, Diesel, Biofuels, Natural Gas, Hydrogen, Electricity
Powertrains	ICE, Hybrid, Plug-in Hybrid, Battery-Electric, Hydrogen Fuel Cell

According to the portfolio perspective, these options are thus assumed to co-exist in the future. The reason for this is that none of the alternatives is completely satisfying for all types of users and uses. It is argued, in the documents mentioned in the introduction, that (plug-in) hybrids and alternative fuel combustion engines can only partly reduce CO_2 emissions, pure battery-electric cars will only satisfy those consumers that drive relatively short distances consistently, and hydrogen cars will be too expensive for most users. As a consequence, those who only drive relatively short distances and do so consequently will adopt BEVs, those who need longer drive ranges will continue to drive ICE's or hybrids and those who can afford it may switch to hydrogen. Furthermore, the biofuels pathway is limited by the availability of feedstock and competition with food production is undesirable. As an illustration we quote from the summary of the 2011 report from the European Expert Group on Future Transport Fuels:

"Road transport could be powered by electricity for short distances, hydrogen and methane up to medium distance, and biofuels/synthetic fuels, LNG and LPG up to long distance." (p.5)

True as the recognized bottlenecks of the potential alternatives may be, underlying the portfolio perspective, in our view, there is also a strongly normative starting point. The reasoning is driven by the perceived need for cleaner cars and the desire to implement them as fast as possible and as widely as possible. In that sense, the portfolio perspective is an idealistic scenario and therefore a matter of wishful thinking.

There is a rhetorical role for this outlook on the future as well. By portraying the future as one of many powertrains and fuels, an excuse is provided for the different alternatives (and their developers and advocates) not too deliver the one-size-fits-all solution. That is, in the portfolio perspective none of the alternatives has to comply with all the criteria that are set by different uses and users: different users can choose the type of car that fits their needs best. E.g. batteries don't need to provide a 700 km range when they are only used by city dwellers and fuel cell cars can be expensive when they are available in the luxury segment and others can drive on biofuels or hybrids.

Furthermore, the portfolio perspective implies that all options can and should be included in research agendas, funding schemes, and regulatory frameworks. If this message is conveyed successfully, the competition between different technologies and their developers is partially postponed and they can frame themselves as colleagues rather than as competitors. Car manufacturers especially have different capabilities and preferences with regard to the set of technological options and for them the portfolio perspective is relatively reassuring as each can follow its own paths and no option is excluded yet.

3 An alternative perspective

Appealing as it may be, the portfolio perspective contradicts starkly the lessons that were learned from studies of innovation dynamics and histories of industrial change. Based on those lessons, one would rather expect that after a period of change, with high technological variation, a single dominant design (re-) emerges (Murmann et al. 2006). Strikingly, the notion of dominant designs was first developed in relation to the car industry and the dominant position of the combustion engine therein (Abernathy et al. 1978). That dominancy was only reached after a period in which multiple, radically different, designs competed with each other. For instance, as Gijs Mom has convincingly shown, the combustion engine fought a serious battle with early electric vehicles (Mom 2004). Without using dominant design thinking as a deterministic model, we aim to sketch a number of its arguments that speak against the portfolio perspective.

Dominant designs tend to emerge as a result of increasing returns to adoption (Arthur 1989). That is, increasing adoption of one design by users results in an increase in the advantages of that design over its competitors. On the supply side, increasing returns to adoption relate to scale benefits, resulting in lower costs due to economies of scale in production and distribution. Furthermore, when more manufacturers are involved and production volumes increase, cost reducing and performance enhancing innovation is likely to increase as well (Rosenberg 1982).

On the demand side, increasing adoption of products brings a number of advantages to new and existing users as well. These advantages are found in so-called network externalities that increase the value of a product to its users (Katz et al. 1994). In the case of passenger cars, valuable network externalities are found first and foremost in the build-up of refueling (or recharging) infrastructures. Additionally, when more consumers make use of a specific design, consumers will profit from the availability of a qualified maintenance network and other after sales services.

Dominant design thinking and the notion of increasing returns to adoption also teaches us that the competition between different designs may be decided by an early lead for one of the competitors. This implies that, in such cases, it is not the always the best design (insofar as one is able to make such a claim) that wins, but rather the first to gain a lead over it competitors, leading to an early lock-in (Hekkert et al. 2005).

3.1 Compatibility and similarity

The arguments that are provided by the dominant design perspective do not necessarily imply that only one design can come to dominate an industry. The two main sources of increasing returns to adoption, economies of scale and network externalities, can provide benefits to more than one design alone. In case a number of designs are highly similar in terms of (core) components or infrastructural needs, they can mutually benefit from each other's economies of scale or network externalities. An early lead for one design may then even provide stepping stones for other, similar or compatible, designs.

Such dynamics can also be expected in the automotive industry. From the wide variety of designs that are being developed today and that are included in the portfolio perspective, we propose to make a distinction between two main clusters of rather compatible and/or similar designs: the *alternative fuels* cluster and the *electrification* cluster.

The *alternative fuels* cluster consists of designs that are based on existing combustion engine powertrains, but use alternatively fuels such as biofuels, natural gas, and hydrogen. In terms of engineering, these designs rely on relatively incremental adjustments of the current dominant designs. Therefore, these cars will profit from the massive economies of scale of current production facilities. On the infrastructure side however, the alternative fuels need to be available at gas stations and this will require substantial investments and hence there will be competition between the different fuels. While some of the fuels, the liquid ones, can be added to existing infrastructure with relative ease, others, the gaseous ones, require much higher investments and face some technical difficulties as well. As said, the availability of refueling infrastructure is the most important network externality and an early lead for one of the alternative fuels in terms of infrastructure build-up could be decisive.

The *electrification* cluster consists of designs in which an electric engine fully or partially substitutes the combustion engine: (plug-in) hybrids, electric and fuel cell electric vehicles. These designs differ radically from current cars, in terms of their core components as well as their energy sources. Among each other these designs share a number of core components such as batteries[1] and electric power management systems. These core components are far from fully developed and a lot can be gained from larger production volumes within this cluster. This goes for fuel cell vehicles as well, even though they also require a separate development trajectory towards cost reductions and improved performance of fuel cells and hydrogen storage systems.

In terms of the necessary infrastructure, (plug-in) hybrids and electric vehicles are compatible with each other as they both require the build-up of a recharging infrastructure. Fuel cell vehicles on the other hand would need their own (hydrogen refueling) infrastructure. The latter, together with the mentioned technological and economical progress, makes that (hydrogen) fuel cell vehicles are challenging in terms of both economies of scale and network externalities. However, we argue that they will profit from developments in batteries and power management systems and that they are complementary to the other electrification design in that they can potentially deliver zero-emission mobility without the range limitations presented by battery-electric vehicles.

Our claim is not that either of these two clusters will be dominant in the future and that no competition whatsoever takes place within the clusters. Rather, we have introduced these clusters to illustrate that increasing returns to adoption are not exclusively applicable to a single design alone and that the competition between the cars of the future is likely to result in the survival of a subset of one of the clusters. Within this subset, an early lead for one of the designs can function as a stepping stone for other designs within the subset.

4 Conclusions and implications

We disagree with the portfolio perspective's assumption that all the cars of the future that are being developed today can and will co-exist in the future. Our alternative perspective, in which only a small subset of options will survive, has two major implications for transport and innovation policy today. First and foremost we argue that the different cars of the future will compete for dominance and the most desirable options are not necessarily the winners of this competition, but rather the subset of options that succeed in gaining an early lead in terms of production capacity and infrastructure build-up. Second, to breach the dominancy of today's car, a more focused approach is likely to be more successful as compared to the wide range of options that are put the fore in the portfolio perspective. That is, to compete with the economies of scale and network externalities of today's cars, the most desirable alternative designs need critical mass as well.

While the portfolio perspective implies that all options should be supported and that specific support for one option does not harm any of the options, our perspective implies that supportive measures should be more focused on the most desirable designs. First and above all, technology agnostic GHG emissions regulation should provide an incentive to the market to develop cleaner cars. Second, the most desirable options will not emerge without specific support, as both economies of scale and network externalities are lacking, and specific measures are needed. One of the risks of technology specific support is that governments are notoriously incompetent in picking winners. However, deciding on the most desirable options, we believe, is less difficult and can be based on a number of basic principles.

We propose to support only those options that are part of the *electrification* cluster. We do so, because a) ICE's are and will always be highly inefficient and their share in transport should ultimately be minimized, b) ICE's emit air pollutants that cause many health problems in densely populated areas, and most importantly c) the electrification of the powertrain paves the way for true zero-emission transport in combination with increasing shares of renewable energy in the energy and electricity mix.

Even though the options from the alternative fuels cluster can help to reduce overall emissions in the transport sector, there is a risk that these vehicles block the successful introduction of electrified vehicles. Insofar as alternative fuels vehicles are necessary anyway for specific niche markets, they are likely to be developed by both the automotive and the energy industry anyway because of their fitness with today's technology and business models, regardless of governmental support. There

[1] Something that may eventually counteract these costs-lowering scale effects is the scarcity of raw materials. This is not necessarily the case but Lithium for batteries and Platinum for fuel cells may become scarce in the case of mass production.

is, we argue, thus no need to continue public support for these competitors of the truly desirable cluster of electric powertrains and governmental action should be focused on the latter.

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