Endogenous Transformation in the Automobile Industry

Manuel Bouza, Silvia Ulli-Beer, Philipp Dietrich, Alexander Wokaun

Paul Scherrer Institut
Dynamics of Innovative Systems
OVGA 115
5232 Villigen PSI
Switzerland
+41 56 310 2441
manuel.bouza@psi.ch

Abstract Established industries develop and mature along continuous trajectories defined by the underlying technological paradigm relevant to serve the value network of the industry. Technological discontinuities and/or preference shifts at the higher levels of the value network may trigger a technological transformation in the industry. Depending on different circumstances, the technological transformation process may have significant impact on the industry, reverting the continuous maturation process, creating new structures and changing the way business is done in the future. Here we describe the transformation process that is evident in today's automobile industry, which we call *Endogenous Transformation*, and compare it two transformation processes previously described in the literature (*Disruptive* and *Radical Transformation*). In an *Endogenous Transformation* process, a new technology is developed in a joint effort by most organizations in the industry to substitute the old technology, with which their value network cannot be served any longer in the future. An important condition for an *Endogenous Transformation* process is that new knowledge can effectively be protected from being freely copied by the competition and that new knowledge is traded between organizations, preventing significant knowledge asymmetries in the industry.

Key Words: Innovation, Endogenous Transformation, Automobile Industry, Knowledge Diffusion, Spillover, R&D Strategy

1 Introduction

Climate change regulations and high oil prices are pressurizing today's socio-technical regime in the automobile industry, based on the internal combustion engine (ICE) technology and liquid fossil fuels. This pressures are expected to increase in the future, anticipating important changes of the underlying technological paradigms in the industry. In our group, we intend to model the automobile industry on a micro-level, to better understand the factors influencing a possible technological change, the possible development paths that such a change can take and the final industry structure it may lead to. We think that this will be of great help for developing efficient policies that facilitate a transition towards a more sustainable propulsion technology with minimal social and economic sacrifices during the transition period. In the following sections, the concepts and dynamical hypothesis that have been developed for system dynamics modeling are described. This work continues the work of Mathias Bosshardt [4, 3] in our group and complements the fleet dynamics with innovation and competition dynamics in the automobile industry.

2 Theoretical Background

An industry is formed by companies organized in a value network producing and commercializing goods or services with the quality preferences demanded by their customers. A value network is defined as a "nested commercial system" composed of supplying, manufacturing and commercializing companies, the scope and boundaries of which "is defined by the dominant technological paradigm and the corresponding technological trajectory employed at the higher levels of the network" [6], i.e. proximal to the final system-of-use. In analogy to the Khunian definition of "scientific paradigm", a technological paradigm is defined as "a model and a pattern of solution of *selected* technological problems, based on *selected* principles derived from natural sciences and on *selected* material technologies" [8]. Technological paradigms always imply a technological trajectory, which is "the direction of advance within a technological paradigm" [8] and along which technological progress can be measured as the improvement of the relevant problem solving variables defined by the underlying paradigm.

Under normal operation and because of competitive pressure, companies in an industry with a stable paradigm will focus on the continuous improvement of their products along the trajectory defined by the underlying technological paradigm of the value network they are serving. In order to increase efficiency and competitiveness, successful routines providing a competitive advantage will be selected and stabilized by organizations [11]. This leads to a maturing process in the industry, where the initial explicitly available knowledge of organizations is continuously embedded into routines and communication channels, so becoming ever more tacit and consequently harder to change [10], and increasing organizational inertia [12]. This is a reason why the further technological development in maturing industries is path dependent and follows the technological trajectory relevant in the industries' value network.

Technological discontinuities in an industry may cause the displacement of the existing technological paradigm by a new paradigm. With the new paradigm, new knowledge and competences become relevant for obtaining a distinctive competitive advantage in the industry, causing environmental turbulence [14] and the reversion of the continuous maturity process [1]. This does not happen in the form of a punctuated change but is often a complex transformation process in which the structure of the industry (number of firms, firm sizes and leading companies), as well as the business models may undergo significant change. During the transformation process, organizations need to make the tacit knowledge embedded into routines and communication channels explicit, before it can be updated and new, more appropriate routines and communication channels established. This organizational transformation is specially challenging and costly for established organizations, often having important competitive implications with the consequence, that they may succumb to new market entrants [10]. Usually, at the beginning new technologies are inferior to the prevalent technologies in existing industries, but often have or promise to have important advantageous characteristics which are demanded in market niches for specialized value networks. Therefore, new technologies tend to be developed by new companies in protected market niches without competing with the established technology and where the users are willing to pay a higher price for the exceptional features the new technology offers [9]. As the new technology matures, it may improve along the variables which are relevant in the value network of the established industry as well, and when costs are reduced, it starts competing with the established technology. This development is further enhanced through the fast technological development of the established technology considerably beyond what the value network actually requires and what customers can exploit and are willing to pay for [6]. Although the new technology may still underperform the established technology, it still complies with the actual needs of the value network but at lower (unit [2]) costs. This results in a rapid switch [1] of the customers in the established value network to the new technology, causing a disruption in the industry where incumbent organizations, which did not foresee the technological potential of the new technology and therefore continued to focus on the further improvement of the established technology (often also as a strategic response to the threat of the new technology), are displaced by the newcomers, which were formerly confined to the specialized market niche [6]. It is apparent that such a disruption leads to a important transformation of the industry structure and a switch of the valid technological paradigm to the new one. But, as the new paradigm is able to comply with the relevant values demanded in the established industry (otherwise disruption would not have occurred), it does not necessarily change or redefine the technological trajectory of the industry in the following maturation process. We call the industry transformation process described above *Disruptive Transformation*, following

[1] Assuming low switching costs.

the notation established by Clayton M. Christensen [6].

Radical technological discontinuities and new paradigms may be either introduced by new market entrants or incumbent organizations in a mature industry, as did newcomers with electronic calculators in the calculators industry or incumbents like Hudson and IBM with the closed steel body in the automobile industry [1] and with the Winchester design in the hard disk industry [6], respectively. While the initial intention for the development and marketing of a radical technology by the innovating organization usually is to better serve the existing value network in a new and innovative way, a radical technology tends to establish a new paradigm in the value network, defining a new technological trajectory with new relevant variables for the future development. Therefore, radical and architectural innovations change the way business is done and "influence the established systems of production and marketing" [1], requiring organizations to reorient, reversing the process of industry maturity and causing industry transformation, similar to the disruptive innovations described above. A good example of this is the closed steel body in the automobile industry, which created completely new relevant values like passenger comfort, room heating and ventilation, which until then were irrelevant because of the open wooden bodies then on the market [1]. Because the radical innovation fulfills the requirements of the value network and is broadly adopted, incumbent organizations in the industry quickly perceive the threat and react to it by reorganizing and building up the required knowledge and competences to absorb and further develop the new technology in order to improve their competitiveness, as did Chevrolet and GM with the closed steel body [1]. Also, new organizations may enter the industry following a technological discontinuity because of lower market barriers [8], posing a significant threat to incumbent organizations that need to reorganize. We call the industry transformation process described above, which is initiated by a radical innovation launched either by an incumbent firm or a newcomer, destined to better serve an existing value network but which will change its valid paradigm and its future technological trajectory, as *Radical Transformation*. What makes it different from the *Disruptive Transformation* is the fact that the relevant improvement variables and the technological trajectory are maintained in the *Disruptive Transformation* [2], while it is changed in the *Radical Transformation* process. What is common to both is that the transformation process is triggered by a technological discontinuity which is available and marketable from the beginning (Figure 1).

Besides the two industry transformation processes described from the literature above, we postulate a third transformation process, which we call *Endogenous Transformation* (Figure1) and which is evident in today's automobile industry. New climate change regulations and fluctuating fossil fuel prices are pressurizing the socio-technical regime of the automobile industry based on the internal combustion engine (ICE) and liquid fossil fuels (gasoline and diesel). These pressures are calling for new drive train tech-

[2]Actually, the new technology is adopted by the value network because it complies with its' requirements but at lower costs compared to the current technology

nologies based on alternative fuels to primarily reduce CO_2 emissions, but also decrease the dependence on oil, causing changes in the relevant variables of the value network and forcing the industry to look for new solutions based on alternative paradigms, as the current paradigm reaches its technological limits (e.g. thermodynamic efficiency). What differentiates the *Endogenous Transformation* process from the former two transformation processes is that an alternative technology to solve the pressure and problems of the current regime is not available, but needs to be developed first.

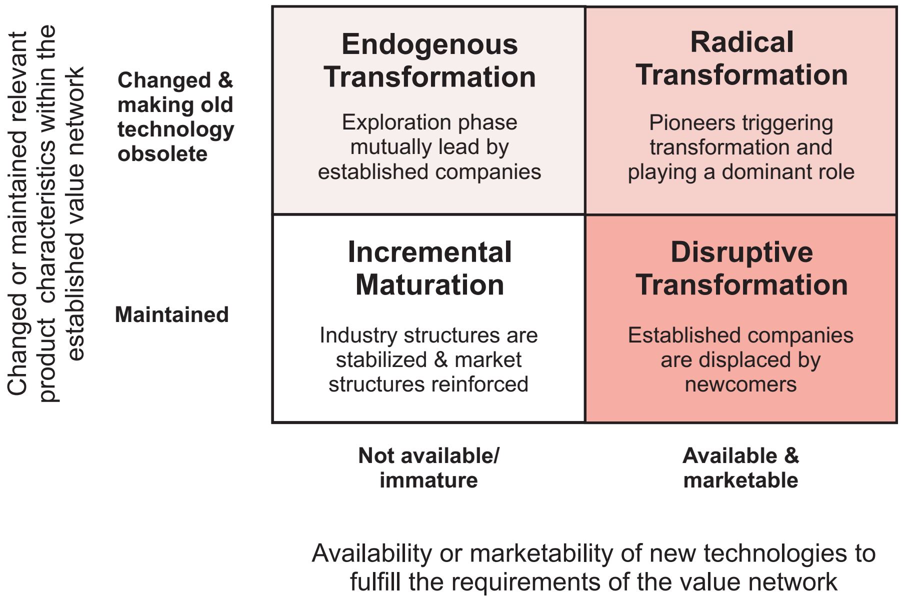

Figure 1: Transformation processes in industries

3 Methods

In order to identify important feedback loops for technological change we developed a first dynamical hypothesis [13] (working paper[5] available on request). Our dynamical hypothesis builds mainly on concepts from the research literature cited in the introduction [8, 1, 14, 10, 6, 9] and can be summarized as follows:

(i) During normal phases of the industry maturation process, organizations focus on continuous innovations and on improving the current technology following the technological trajectory given by the relevant paradigm in the value network

(ii) New technological discontinuities which could better serve the value network or pressures on the current socio-technical regime of the value network may cause organizations to change the focus from continuous innovations to develop radical innovations

(iii) A focus shift from continuous to radical innovations requires incumbent organizations to reorient, which is a difficult and costly organizational process

(iv) The industry enters a ferment exploration phase characterized by technological and market uncertainty and in which different designs are developed and marketed by different organizations; usually, this is accompanied by newcomers entering the market due to lowered market barriers

(v) When a new dominant design emerges, i.e. is successfully selected by and penetrates the market, the ferment exploration phase comes to an end

(vi) The whole industry focuses again on the continuous improvement of the dominant design following the trajectory defined by the underlying new technological paradigm

(vii) Pioneering companies successfully developing and marketing the dominant design become the new leaders in the new industry era

(viii) The industry follows either a *Radical* or *Disruptive Transformation* process, depending whether incumbent organizations recognize the potential of the new technology to serve their value network or not, respectively

In order to verify the dynamical hypothesis, we have conducted several interviews with automobile industry members (N=3) and experts (N=2). In the following we describe the results and conclusions obtained from the interviews and the underlying systemic mechanisms that drive the whole industry to develop a solution in a common effort from within, leading to the postulated *Endogenous Transformation* process, as can be evidenced today.

4 Interview Results

The automobile's industry regime based on the ICE technology and liquid fossil fuels is under pressure. Mainly regulatory requirements for the reduction of green house gas emissions, which are expected to tighten in the near future, and possible fuel price fluctuations, exert the pressure on the current ICE regime. This pressure is causing a focus change from improving the ICE technology alone to also develop alternative drive train technologies for their future commercialization. It is estimated that the ICE technology will not be able to fulfill future market requirements after the next 10 to 25 years and that an automobile manufacturer focusing on the improvement of the ICE technology alone will not be able to sustain a competitive advantage after the same period.

Organizational change costs (e.g. build up of new competencies in R&D and marketing teams, write-off of obsolete infrastructure and investments into new infrastructure) are not regarded as an impediment for the development of alternative drive train technologies.

Investments into the development of alternative drive train technologies have mostly started around the year 2005 and are expected to increase. Between 2012 and 2020 the share of R&D expenses for alternative drive train technologies will have reached 50% of total R&D expenses, as estimated by automobile industry members. Automobile industry experts estimate this to happen only between 2030 and 2040. In general, it can be expected that R&D expensed for alternative drive train technologies will increase to a significant share in the next years to come. By 2050, little if not nothing will be expended for the further development of the ICE technology.

Patents are effective means to protect new technological developments from the competition. It is very usual between automobile manufactures to trade patent licenses, as is the case with Toyota's hybrid technology and Ford's Diesel technology. Knowledge diffusion is high in the automobile industry, meaning that new technological developments are quickly absorbed and applied by the competition as well, but it is bidirectional, meaning that an automobile manufacturer can only benefit from this knowledge diffusion if it has something to offer on its own. Other means of protecting new developments are secrecy, i.e. keeping the knowledge in-house without patenting it and making it public. Speed to market and the image of technological leadership are key factors to obtain a competitive advantage in the highly competitive automobile industry.

The following alternative drive train technologies are regarded as having the greatest potential to have a market share of over 20% by the year 2050 (ranked by highest potential):

(i) hydrogen fuel cell

(ii) battery electric

(iii) electric-gasoline hybrid

(iv) electric-natural gas hybrid

(v) alternative liquid fuels (e.g. bio-ethanol, bio-diesel) with ICE.

(vi) natural gas ICE.

Here it must be noted that the technologies have been rated quite differently (high standard deviations), this being symptomatic for the uncertainty prevalent during the exploration phase and it is yet unknown what technology will be best suited for future marketability, i.e. fulfilling individual mobility requirements at affordable costs compared to today.

5 Conclusions

Both tightening green house gas regulations and changing customer needs [3] are pressurizing the current socio-technical regime of the automobile industry and transforming it's value network. Automobile manufacturers have become aware of these changes and they regard alternative drive train technologies as a solution to solve the current pressures

[3]Increasing preferences for small and energy efficient cars can be observed

and meet future market requirements, despite the challenging and costly reorganizations that they imply. This awareness and change of strategic orientation creates sufficient drive to overcome organizational inertia[12] reducing the inner-organizational resistance to and costs of change. From this it can be concluded that a *Disruptive Transformation* process is unlikely to happen in the automobile industry and consequently, that new automobile manufacturers offering vehicles based on alternative drive train technologies will have a difficult stand to compete against incumbent manufacturers.

Because of the significant knowledge trading between organizations in the automobile industry, the need to undertake own R&D efforts is specially high for companies. If a company does not research and develop new technical knowledge, it is excluded from the knowledge trading process, increasing it's technical gap significantly with time. This may also explain why most leading automobile manufactures are investing significantly in the R&D of alternative drive train technologies. An additional motivation for these investments may be the build up of absorptive capacity [7] and the resulting capabilities to perceive and quickly react to technological developments and breakthroughs of competitors in alternative drive train technologies. The high risk of a car manufacturer to solely pursue the development of an alternative drive train technology, as well as the consequences of not partaking in the development of alternative drive train technologies other car manufacturers are pursuing (both excluding the car manufacturer from the knowledge trading process and increasing the technological gap) may lead to the creation of a common focal point in the industry, where the development of a selected alternative drive train technology is emphasized by all manufacturers at the same time. This may explain the congruent efforts undertaken by the leading car manufacturers to develop and commercialize battery electric cars today. Depending on how successful this commercialization will be, these efforts are either continued and intensified or abandoned. In the latter case, this would probably lead to the formation of a new focal point, putting emphasis on another alternative drive train technology in the future, starting the whole process again and prolonging the *Endogenous Transformation* process.

Bringing all these different aspects of technological transformation in today's automobile industry together, it can be concluded that the following is necessary for an *Endogenous Transformation* process to develop:

(i) A mature, knowledge intensive and highly competitive industry with a stable socio-technical regime exists

(ii) Overlying economic, sociological and/or ecological systems put pressure on the current industry's socio-technical regime, causing a shift in the values of the industry's value network

(iii) Further improvements of the current technology is not a solution to solve the pressure, either because it is the cause of the problem itself (e.g. dependence on oil) or because it is reaching it's technological limits and further improvements are prohibitively expensive (e.g. thermodynamic efficiency)

(iv) Incumbent companies in the industry realize that, in order to solve the pressure and to fulfill future market requirements, a paradigm change is necessary (making a *Disruptive Transformation* process very unlikely)

(v) No alternative technology is available to substitute the old technology and solve the pressure; possible alternative technologies exist, but are yet immature to be commercialized and need to be developed first

(vi) No sudden, unexpected and radical technological breakthrough occurs, i.e. alternative technologies evolve gradually and without creating significant knowledge asymmetries between companies in the industry (otherwise the transformation process would become a *Radical Transformation*

(vii) New knowledge can be effectively protected from being freely copied by the competition and is traded in the industry; this prevents significant knowledge asymmetries in the industry

In Figure 2 the factors and dynamic structure leading to an *Endogenous Transformation* process are shown in a casual loop diagram [13]. The interview results allowed us to refine the most important loops (six reinforcing and three balancing loops), which are listed and described in Table 1.

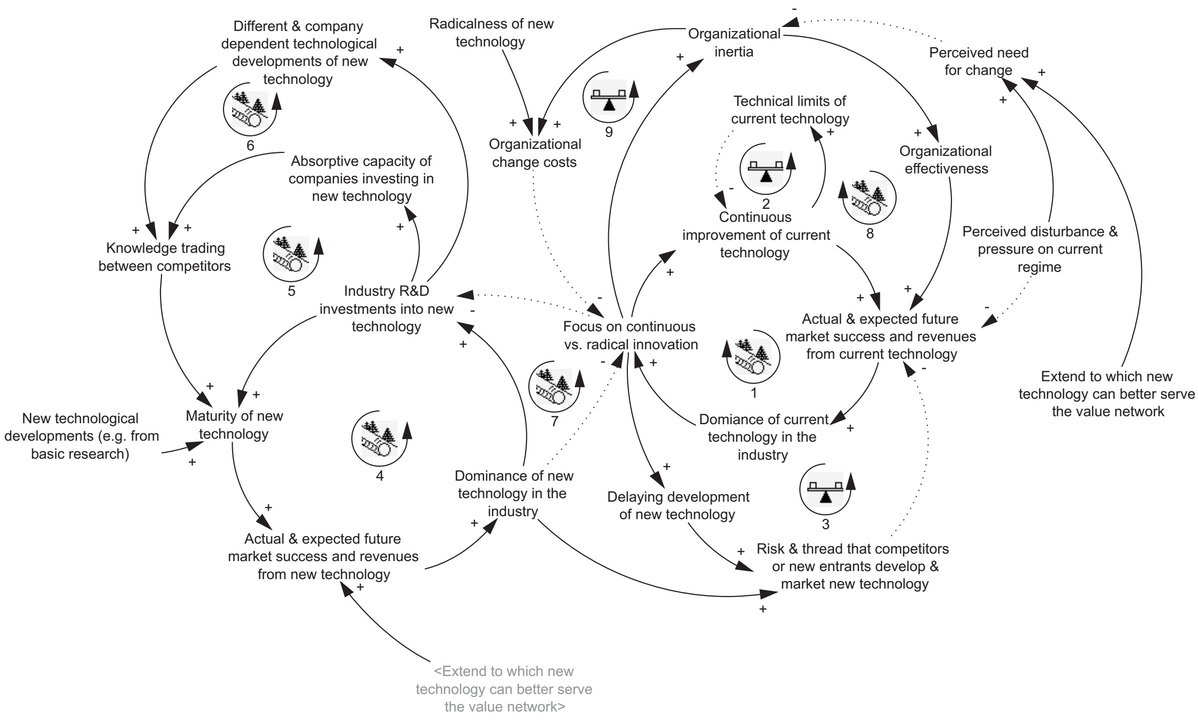

Figure 2: Casual loop diagram of *Endogenous Transformation* process

Table 1: Feedback loops of casual loop diagram

Nr.	Loop Name	Polarity	Description
1	Technological Trajectory	+	Focus on continuous innovations improves current technology and increases current and expected future market success, as well as current technology dominance
2	Technological Limits	-	Reaching the limit of the current technology reduces marginal improvements and makes continuous innovation unprofitable
3	Competitive R&D	-	Danger or the perceived risk that competitors or new entrants develop the new technology decreases the expected future profits from the current technology and so favors a focus shift towards the development of new technologies
4	Technological Maturity	+	Initial R&D investments leads to increased technological maturity, which increases actual and expected future market success and revenues from the new technology, given that it fulfills the requirements of the value network
5	Absorptive Capacity	+	Technological uncertainty motivates companies to invest into different technologies to develop absorptive capacity and to be able to perceive and react to new technological developments of competitors; absorptive capacity facilitates absorbing new knowledge and favors knowledge trading

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Table 1 – *continued from previous page*

Nr.	Loop Name	Polarity	Description
6	Knowledge Balancing	+	New technological developments are traded between competitors resulting in bidirectional knowledge diffusion, avoiding significant knowledge asymmetries in the long run and increasing the maturity of the new technology
7	Technological Dominance	+	Technological maturity of the new technology increases it's technological dominance, increasing a focus shift towards the development of new technologies and so motivating even higher R&D investments for the new technology
8	Organizational Effectiveness	+	Focus on continuous innovations increases efficiency and consequently current and expected future market success
9	Organizational Inertia	-	Focus on continuous innovations increases organizational inertia[12], resistance to change and organizational change costs

6 Outlook

Our dynamic hypothesis will be further refined with ongoing interviews of automobile industry members and experts. The following steps will be the development of a system dynamics model with game theoretic concepts to simulate the competitive dynamics under an *Endogenous Transformation* process in the industry on a micro or firm level. The purpose is to develop effective policies which support a smooth transition towards sustainable alternative propulsion systems with low green house gas emission under minimal social and economic transition costs.

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