Citizens' Choice: Modeling long term technology transition in the automobile industry

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Abstract

The transformation process towards sustainable road transportation implicitly requires that household's car choice is not only influenced by individual or household specific objectives but also by societal objectives such as mitigating climate change. Hence the car purchase decision is seen as a citizen choice process, also including societal and ecological aspects in the decision function. The automobile industry is already in the process of changing its research and development paradigm towards energy-efficient drive-train technologies – but the process of how and how fast citizens will respond to this paradigm change is still unclear. Based on theoretical and empirical evidence the paper suggests firstly, a conceptual technology transition framework explaining changes in citizens' choice process. The framework highlights why traditional choice models (such as logit models) may not be able to simulate the transformation process towards sustainable road transportation correctly. Secondly, a simple dynamic choice structure will be suggested that is able to simulate discontinuous change in citizens' car choice pattern.

Keywords: technology transition, choice model, diffusion model, paradigm change, social norm, preference change, alternative drive-trains

Introduction

Today, light duty vehicles account for around 45% of total transport energy use world wide (see also Ribeiro, Kobayashi et al. 2007, p.11). Hence the implementation of energy-efficient technologies and non-fossil fuels are critical for combating climate change. The automobile industry is taking the new challenge seriously and is triggering a paradigm change in research and development efforts. They develop new drive-train technologies combined with alternative fuels in order to reduce their dependence on fossil fuel and to meet CO_2 reduction targets. The automobile industry and policy makers, however, do not know firstly, how private car users will respond to emerging development trajectories – and secondly, if emission reduction targets can be met timely or how strong and how long supporting policy measures are suitable.

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Different studies and modeling projects are trying to shed light on possible diffusion paths of alternative drive-train technologies and fossil fuel consumption scenarios over a long time horizon up to 100 years without having a clear understanding about inherent system inertia and the basic mechanisms that are forming consumer preferences regarding alternative drive-trains (Bandivadekar and Heywood 2004; Krzyzanowski, Kypreos et al. 2007; Mueller and Haan forthcoming). Hence, there still remains a vast uncertainty concerning how long it may take alternative drive-train technologies to reach a desired market share. Geroski (2000) argues that the inherent difficulties of this question are the many people making interdependent decisions and that a basic reference point is missing that would help to grasp the diffusion rate. While most technology diffusion models are able to simulate an s-shape take-off development path[2], they are not able to address the phenomenon of a tipping point or a critical mass that would determine if a new technology will fail or succeed in the market (Bosshardt, Ulli-Beer et al. 2006; Phillips 2007). More specific diffusion models include information cascades that are driving the bandwagon-effect, depending on the initial technology choice and on net-work effects. Although pioneers may be very important for a first market entry and for legitimating the technology (Geroski 2000), they may not be the decisive first users that determine if the technology will really take off. The followers or the so called early adopters (Rogers 2003 5th Ed.), undergoing a learning process concerning the appropriate technology in a changing environment, may be more important, since they may build up further reinforcing decision cues determining the choice context of late followers. One such decision cue could be the perceived social norm for adopting an alternative technology (Ajzen and Fishbein 1980; Schwartz and Howard 1981).

The paper builds on this line of reasoning in order to answer the question, how citizens respond to technology change in the automobile industry. Combining different schools of thoughts on choice (e.g. Ajzen and Fishbein 1980), change (Dosi 1982; Argyris and Schön 1996), and different adopter categories (Rogers 2003 5th Ed.) a coherent technology transition framework will be introduced that differentiate static choice contexts versus continuous and discontinuous acceptance dynamics (Gassmann, Ulli-Beer et al. 2006). The framework helps to address the following research questions.

- What are basic context characteristics that may lead to preference changes or discontinuous choice dynamics?
- What are typical observable time constants that may help to grasp the rate of adoption?
- How can discontinuous choice situations or preference changes be modeled?

Building blocks of a technology transition framework

In order to answer the question, how citizens respond to technology change in the automobile industry, most fundamental concepts that have explanatory power for the question at hand must be understood.

Firstly, one important conceptual layout is indicated by using the term citizens instead of consumer or household. The transformation process towards sustainable road transportation implicitly requires that household's car choice is not only influenced by individual or household specific objectives but also by societal objectives such as mitigating climate change. Hence the car purchase decision is seen as a citizen choice process, also including societal and ecological aspects in the decision function. The distinguishing criterion for using the term citizens is not the character of the good (i.e. public or private good) but the existence of a public interest or threat caused by a good and the existence of a political agenda (see Ulli-Beer p. 11).

[2] For a review on models of diffusion see Geroski (2000).

Secondly, at the individual level psychological theories offer useful ways for understanding how people interpret information about their environment and how they will respond on the basis of these understandings (see Stern 2000). Two empirically well supported theories explaining and predicting human behavior in specific contexts is the theory of planned behavior (Ajzen and Fishbein 1970; Ajzen 1991) and the altruism model (Schwartz and Howard 1981). While the theory on planned behavior highlights the role of the personal norm (what the person himself thinks is the right thing to do) on the decision process, the altruism model explains the influence of the social norm (what significant others think is the right thing to do) on the personal norm. When the awareness of a problem and the ascription of responsibility are high a social norm will translate into behavior. While these concepts may be helpful in understanding a static choice situation they may not help to understand how new norms may be formed.

Thirdly, Argyris and Schön (1978) as well as Dosi (1982) are addressing change processes in similar ways distinguishing short term from long term adjustment processes. Argyris and Schön's model on double-loop learning are distinguishing two different learning loops: First, a simple error detection and correction loop within a fixed goal and value context called single loop learning. Second, the double loop learning process which describes an error correction process that involves the modification of the governing variable. This variable may be the underlying norm, guiding policies or objectives. Hence goals and behaviors are adjusted to changing environments. Dosi (1982) distinguishes two different drivers of technology change (see Figure 1). Firstly, incremental innovations where a continuous technical change process follows a technological trajectory defined by a technological paradigm. A technology paradigm is seen as a typical solution pattern for selected technological challenges; e.g. increasing the energy-efficiency of a combustion drive-train. Secondly, radical innovations where a technological progress is guided by the emergence of a new paradigm, that is appropriate to address new challenges evoked by long term consequences of an old technological paradigm such as climate change issues.

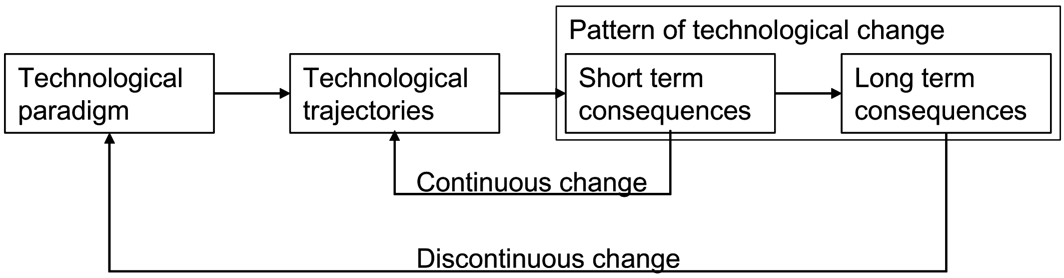

Fig 1: Illustration of the technology change model based on Dosi (1982). Technical progress is guide by a specific technological paradigm, resulting in technological trajectories that improve the technology corresponding with the existing needs of technology users. The prevalent short term consequences (higher profits or market shares) due to meeting the actual needs are controlling and fine tuning the technological improvement process along technological trajectories. However, long term consequences such as climate change are triggering the emergence of a new technological paradigm. This overriding change process is called discontinuous change.

While neither the technology change model, nor the double-loop learning approach or the psychological decision model alone may give a comprehensive understanding on how citizens may respond to technology change, they may guide the development of a coherent explanation framework that combine static with dynamic concepts of technology adoption.

The technology transition framework

The quest to get an appropriate theoretical framing for the question at hand involves also a simplification of reality. In order to detect dynamic pattern of behavior a particular distance is required that blurs the single decision process of individuals into a flow of cause and effects and helps to perceive general guiding policies that can be endogenously modeled (see Richardson 1991:333ff). However, the theoretical framework should be able to explain typical observed phenomena such as strong system inertia and slow transition processes. Also it should be helpful to understand which diffusion and decision model would be appropriate for the research task. In the following such a transition framework will be described.

Due to the prevalent customer demand the old technological paradigm in the automobile industry is characterized by increasing power and growing vehicle dimensions (Dudenhöffer. 2004). In spite of increasing energy efficiency of drive-trains the above mentioned technological trajectories are triggering a rebound effect (Schipper 2000) on fuel consumption in upstream decisions or a performance-size-fuel consumption trade-off (Bandivadekar, Cheah et al. to be submitted in Energy Policy).

These technological paradigms are becoming prevalent in the car fleet as a typical behavior pattern and a perceived social norm. The social norm triggers again the subjective norm telling the potential buyer that high-powered cars is a good thing to have. In spite of high fuel consumption, the bulky, high-powered car may convey a high satisfaction due to different psychological aspects (e.g. safety feeling). This again is confirming the willingness to accept a bad fuel economy (see Figure 2).

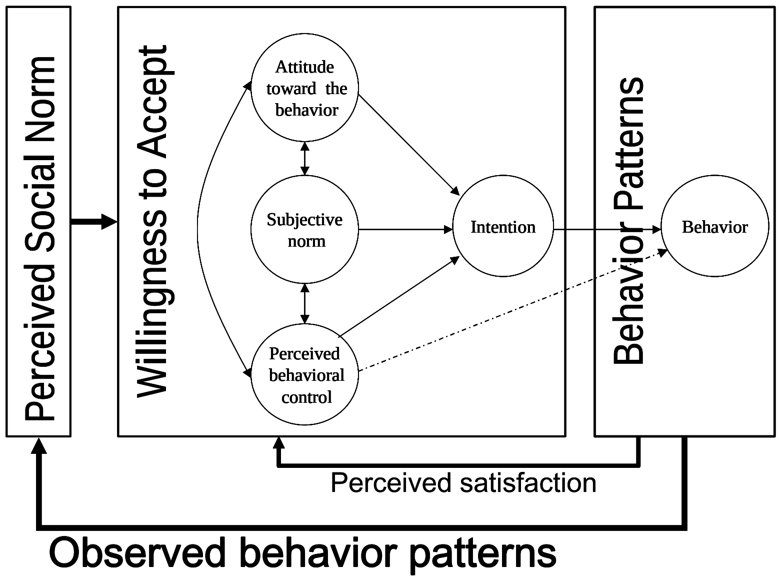

Figure 2: Citizens' acceptance dynamic: The technology choice process is locked in by two different loops. First, a short term operating personal evaluation loop where the perceived satisfaction is controlling the willingness to accept the technology at the individual level. Second, a long term operating social norm loop, where observed significant social behavior patterns will act as decision cues guiding again individual choices. The social norm loop has an overriding effect; therefore it is acting as the guiding policy at the social level for car purchase decisions.

The perceived satisfaction loop and the observed behavior pattern loop explain a socially determined lock in effect that is stabilizing a dominant technological paradigm (see also Arthur 1989). They do not explain how technology users respond to new technological paradigms that are triggered by undesired long term consequences of prevalent technological paradigms. However, significant long term consequences may also trigger the emergence of a new social norm concerning alternative technological paradigms that address new challenges such as global warming. Hence, the emergence of a new appropriate social norm may lead pioneers and early adopters to consider alternative technologies. The early adopter categories are crucial for the establishment of the new appropriate social norm; however this takes time and may even be a nonlinear process (see the proposed mathematical Function 1).

(1) $\textit{Fraction from adopters norm} = \textit{adopters}^2 \;\; k$, where k is the effect of adopters' norm

Nonlinearity arises from perception delays of new choice patterns. If only pioneers and early adopters are buying alternative technologies, they may not offer significant decision cues to others, or the new cues are not yet perceived since they are not dominant. In such a case we could observe discontinuous change characterized by the existence of a critical mass or a threshold before a new perceived social norm becomes strong enough for guiding the choice process in the mass market. In the case of a linear relationship between first movers and the perception of a new behavior pattern we could speak about continuous change (see Figure 3).

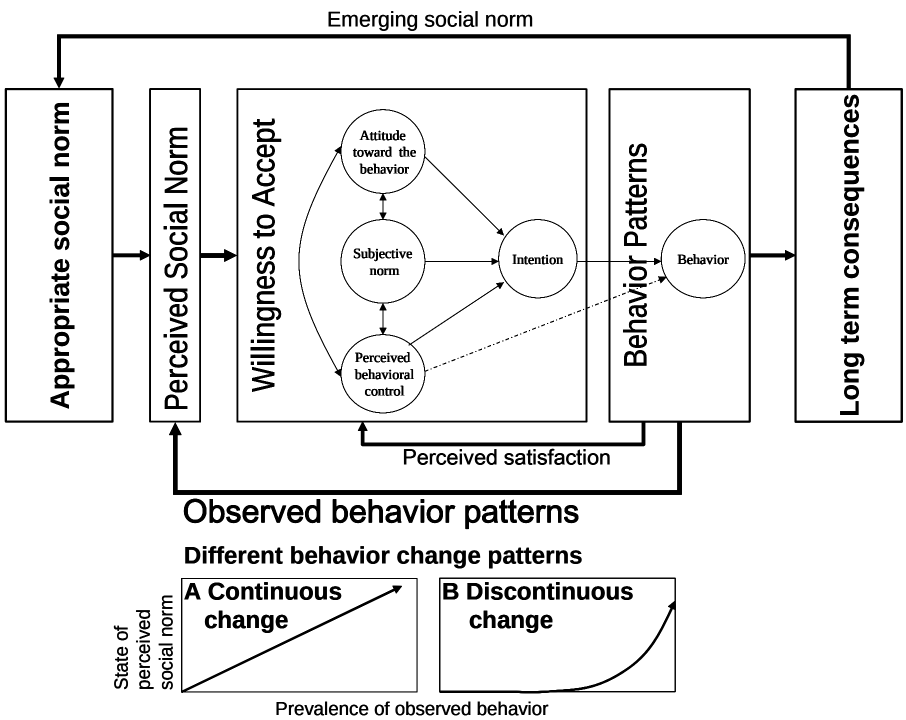

Figure 3: Citizens' technology transition framework: Undesired long-term consequences are provoking the emergence of a new appropriate social norm. Hence, pioneers and first movers induce slowly a new behavior pattern that may be perceived as a new social norm by following adopter categories leading to a continuous change pattern if perceived proportional to the number of adopters. The more realistic case would be a nonlinear relationship between the prevalence of a new behavior pattern and the perception of a new social norm leading to discontinuous change.

The technology transition framework highlights the relevance of different adopter categories for the emergence of a new social norm and the technology transition process, respectively.

Given a continued succession of the adoption along the categories from innovators, early adopters, early majority, late majority and laggards driven by a new emerging appropriate norm, we can guess a first reference point for the length of the technology transition process; e.g. the average life of cars may indicate how long it will take to replace the old technology within one adopter category. Having only the social norm building process as the guiding social policy, it may take three times the average life span till half of the car drivers have adopted the alternative technology (see Figure 4). The penetration within pioneers may be the legitimating process of the alternative drive-train offering first decision cues to early adopters that this technology may become an appropriate solution for sustainable road transportation. The early adopters may form significant decision cues to the early majority. This group is learning that a new social norm is evolving. As soon as the early majority has adopted the alternative drive-train technology, this technology may now be prevalent enough within the car fleet to form the dominant social norm. Then, it can start guiding the decision of the late majority and the laggards.

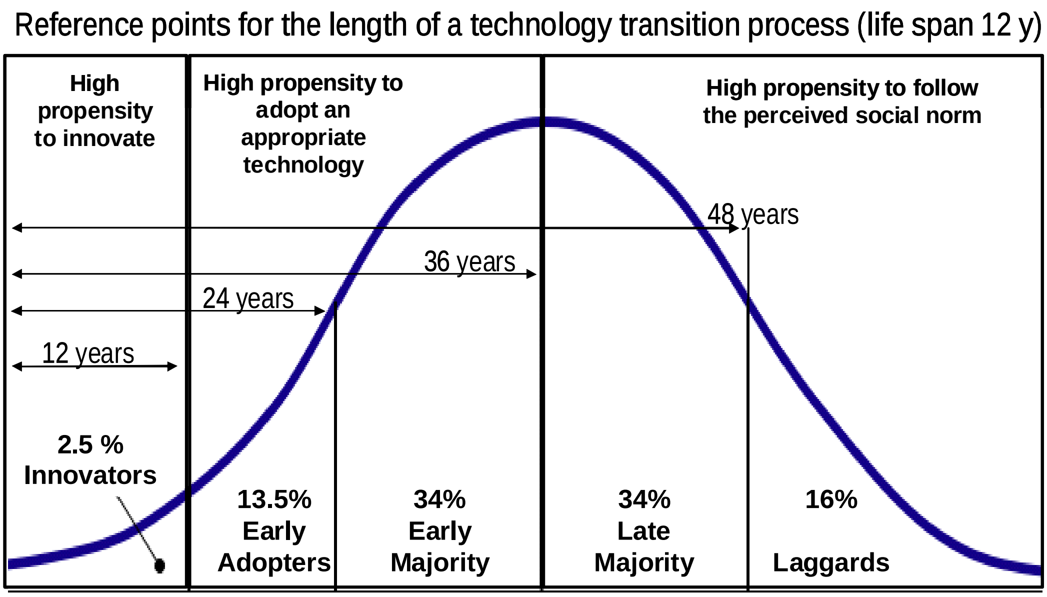

Figure 4: The average life span of the technology carrier becomes a first reference point indicating how long it will take an alternative technology to pass through the different adopter categories. In the case of alternative drive-train technologies it may take up to 36 years till half of the drivers may be driving it, if the transition process is primarily moderated by a social norm.

In order to reproduce the corresponding adoption curve representing s-shape growth (Figure 5), the ideal typical adoption succession along the categories can be translated in required market share ranges. Either a simple stock and flow model or mathematics helps to determine the required market share by solving the differential equation for the adoption curve. The market share graph has a skew bell-shape, highlighting the long lead-time to mass-market (up to 30 years). Over time the stock of potential new adopters gets depleted, meaning that the technology transition has reached its new equilibrium. At this point the market is again mainly driven by repeated purchase decisions guided by the satisfaction loop.

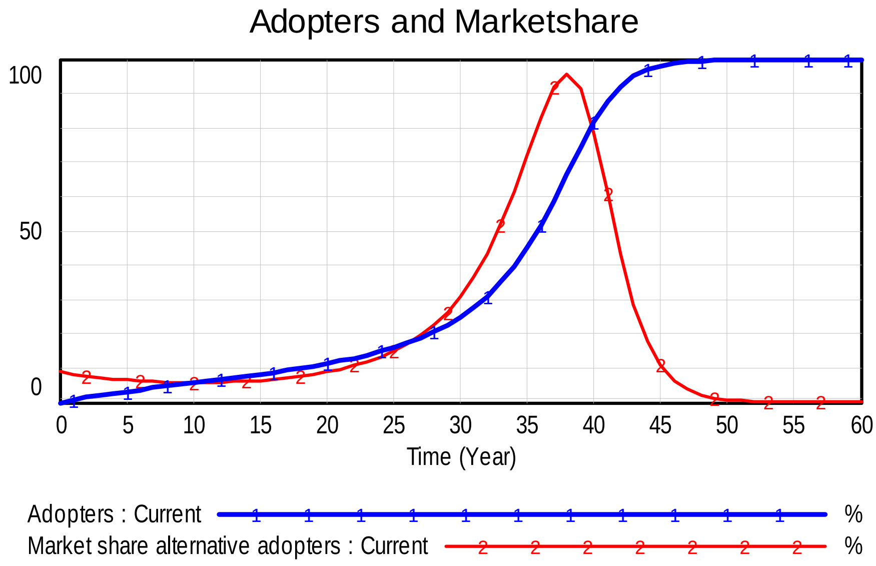

Figure 5: Adoption curve and market share development: Showing the level of adoption with its specific adoption rate or market share, respectively.

To sum up two remarkable reference points seem worth mentioning (see Table 1). First, it takes twenty years till a fleet share of approximately 10% can be reached requiring a market share between 5% and 10%. Second, the next twenty years is characterized by a very strong raise in market share starting from 10% and raising up to 100%.

Years	1-10	11-20	21-30	31-40
Market share range %	0-5	5 - 9	9 - 31	36 - 96
Market share of SUVs	0 - 5.1	5.1 - 12	12 - 26.3	
Market share of Hybrids (only first 5 years)	0 - 1			

Table 1: Plausible market share ranges of the technology transition over a time horizon of 40 years given a vehicle life span of 12 years and empirical market shares of SUVs (Davis and Diegel 2007) and Hybrids in the USA (sales data from Toyota).

Consequences for modeling long-term technology transition processes

The introduced technology transition framework becomes useful guiding modeling exercises that aim at analyzing different diffusion paths of societal desirable alternative technologies. It points out that a competitive technology paradigm change requires preference changes from the user side concerning new appropriate technologies. In such a situation logit or probit models that are calibrated within the old technology paradigm being consistent with the economic assumption of stable preferences may have shortcomings for analyzing different diffusion paths. Logit and probit models may be characterized as static and reversible decision models, based on perceived satisfaction. Stable preferences are represented by constant coefficients meaning that the general attitude towards different technologies does not change over time (see also Train 2003).

Contrarily, during profound technology change processes which involve user preference changes, dynamic choice models are required that include emerging social norm building processes. These must feature two basic characteristics: firstly, preference changes must be endogenously modeled and secondly, the inherent attractiveness of a technology regarding the respective societal challenges has to be given exogenously. In optimization models the inherent attractiveness of a technology is normally considered by objective functions such as a constraint on CO_2-emissions. In descriptive simulation models the intangible technology value becomes a determining initial input factor that represents the technological attractiveness for promoters and first users not depending on the choice of previous users.

In the following a simple dynamic choice structure for simulating technology transition processes in the automobile market is proposed (see Figure 6). The perceived attractiveness of alternative drive-trains can be determined by common product attributes including economic parameters such as fuel and purchase price. These product specific attributes may be modeled as logit functions. However, the desirability of a specific drive-train technology is influenced by the inherent attractiveness of the drive-train technology and the perceived social norm. The share of the specific drive-train technology within the fleet is the indicator for the strength of a social norm concerning the appropriate technology. This link between the vehicle stock with a specific drive-train technology and the social norm building process forms a reinforcing loop. Hence, this loop is either locking the system into a prevalent technology trajectory or reinforcing an emerging social norm depending on the competition between the outdated and appropriate technological paradigm. The median lifetime of the technology carrier determines not only the discard rate but also how fast an outdated social norm will fade away.

Due to the reinforcing loop it becomes clear how resinous the establishment of a new social norm must be. If the inherent attractiveness is not strong enough, the new technological paradigm will never get a chance in the market. However, the inherent attractiveness can be reinforced by different policy and marketing initiatives. Ulli-Beer, Gassman et al. (2008 (under revision)) introduce a generic structure to simulate acceptance dynamics that highlights the behavioral implications of two competing social norms creating different stable equilibria in a system. The simulation framework demonstrates the effect of a tipping point and basic characteristics of transient forces leading the system towards a new equilibrium. The same characteristics can be found in the proposed dynamic choice structure of the competing alternative drive-train technology model developed by Bosshardt et al. (2008).

In the automobile market the perceived satisfaction of new drive-train technologies depends also heavily on the spectrum satisfaction concerning different types of vehicles as well as on the fuel availability satisfaction. Hence a concerted implementation of the fueling infrastructure as well as of different vehicle types are additional reinforcing loops and nonlinearities (Janssen 2004; Struben 2004; Struben 2005; Janssen, Lienin et al. 2006) that imposes further challenges on the introduction of a new drive-train system. For a profound discussion on the model including further reinforcing loops, its behavior and policy results see (Bosshardt, Ulli-Beer et al. 2008 (forthcoming)).

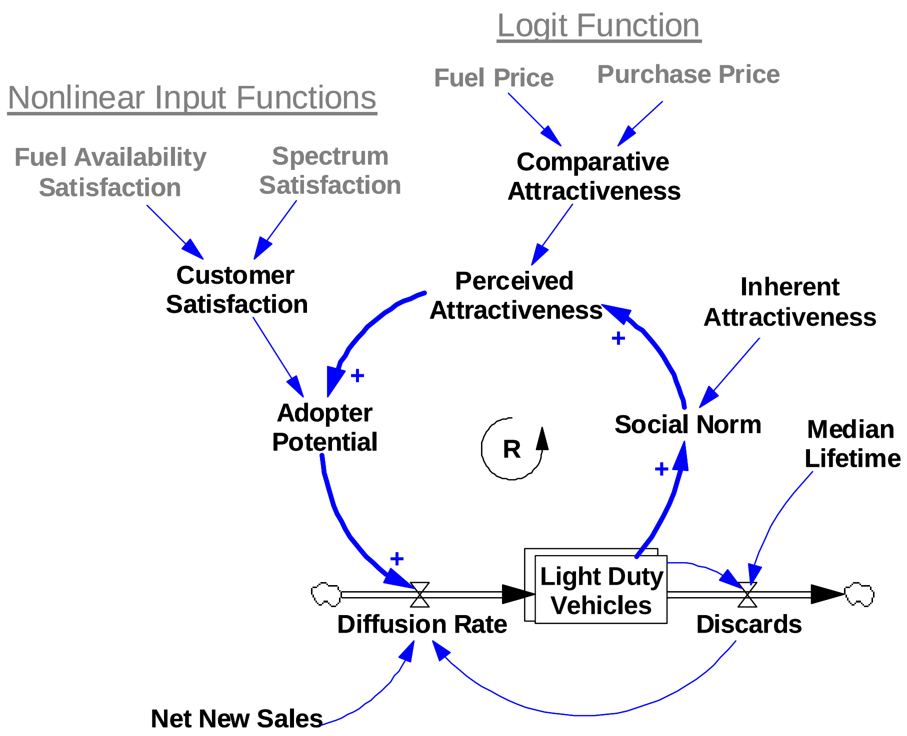

Figure 6: The simple dynamic choice structure. The composition of the <Light Duty Vehicle> stock is determined by the <Diffusion Rate> or market share of alternative drive-train technologies. The <Discards> are either replaced by repeated purchase decisions or adoption decision for new drive-train technologies. <Net New Sales> determine the actual growth of the total <Light Duty Vehicles> fleet. The accumulations of alternative drive-train technologies determine the nonlinear effect of the <Social Norm> concerning the appropriate technology. The comparative attractiveness determined by fuel and purchase price of the different drive-trains computed with a logit function can be boosted by a reinforcing norm building process, depending on the prevalent social norm regarding the appropriate technology. The actual adopter potential however is also determined by the <Spectrum satisfaction> of the different drive trains and their fuel availability satisfaction.

Discussion, policy conclusions and further research

The paper introduces a coherent technology transition framework for the demand side that combines psychological decision making, organizational, and technological paradigm change concepts with diffusion theory. In the following we will reflect on the insights derived from the conceptual analysis of the research questions, how citizens respond to technology change in the automobile industry.

Firstly, basic context characteristics for citizens' choice were identified that point towards preference adjustment processes that need to be taken into account for modeling the diffusion of alternative drive-train concepts. While learning curves reflect the reduction of high initial technological investment cost with the accumulation of experience with a new technology on the supply side, emerging social norms concerning a new appropriate technology may lead to preference changes influencing the willingness to pay for new technologies, and hence resulting in higher acceptance over time on the user side. However, such a socio-technological change process must be triggered by a very strong evidence of undesirable long term consequences stemming from existing technological trajectories and the evidence that alternative technologies become societal desirable. Otherwise the existing social norm remains dominant. In this case, the assumption of stable preferences and respective choice models remain appropriate.

Secondly, typical time constants with their plausible market share timeline have been highlighted. The concept of adopter categories, nonlinear emerging social norms together with the life span of the technology help to grasp typical dynamic adoption patterns that explain why it may easily take up to 36 years till an adoption share of 50% can be reached. Since the social norm effect is reinforcing and triggers exponential growth of the adoption share, the further growth up to 100% could be reached faster. This scenario shows that a product life time is much shorter (12 years in the case of road vehicles) than a societal life time of an outdated norm influencing the market share. However, this adoption process of alternative technologies may be accelerated by different measures. High policy leverage points are discussed further below.

Thirdly, the proposed simple dynamic choice structure for simulating technology transition processes representing the user side is seen as a building block for technology diffusion studies. While a simulation-technical solution has been suggested for implementing preference changes into diffusion models, the dynamical choice structure remains compatible with existing choice and diffusion models that help to differentiate adoption shares between different segments; for example a SUV-driver will remain a SUV-driver but accepting an alternative drive-train technology.

This element points to a further important aspect of the proposed technology transition framework. While it aims at explaining preference changes between different technological paradigms it does not intend to propose switches between different segments that are underlying different vehicle types (SUV, medium sized vehicle or compact cars) or inherent preferences towards horse power. Contrarily, it is assumed that these segments stay stable – a sportive driver will remain a sportive driver even if he would accept an alternative drive-train technology. This assumption becomes very relevant if different measures are discussed for CO_2-reduction. In the following, based on the transition framework, basic policy and strategy deliberations are discussed: The three main leverage points are, increasing comparative attractiveness, fostering the perception of inherent attractiveness, and smoothing the discontinuous preference change process.

Firstly, increasing the comparative attractiveness by financial incentives on fuel price or purchase price becomes most effective if real alternative technical choice options exist that meet the different demands of a very heterogeneous group of car-drivers; e.g. a bonus malus system should reward sportive as well as compact car drivers with an alternative drive-train technology and should punish sportive and compact car drivers with out-dated technologies emitting much more CO_2: Such a policy initiative would support the general technology transition process within all significant segments.

Secondly, the inherent attractiveness and the desirability of new technologies can be highlighted. There exist different measures that would be appropriate. Persons of high public interest can act as model persons or vehicles with alternative technologies may get special tax conditions or area access permits. While these measures may induce higher administration cost and local coordination efforts, they may be most effective because they will foster the emergence of the new social norm guiding further car purchase decisions. The project “New Ride”, a concerted promotion of electro bikes, may be considered as one such intervention measure (Bernhard, Hofmann et al. 2008; Hofmann and Bruppacher 2008 forthcoming).

Thirdly, a discontinuous social norm building process can be absorbed by the introduction of bridging technologies fostering a more continuous change process. However, also these technologies may have a very long lead time due to other nonlinearities stemming from the supply side. Even worse, it could happen, that bridging technologies could lock the system into an inferior state, without being able to reach the policy goals such as CO_2 reduction targets. Hence, a critical condition for promoting this strategy would be the existence of decisive technical spillovers between the bridging technology and a more promising one. Since the automobile industry has very strong inertia with long delays, it may even be more efficient and effective to follow an aggressive change strategy by fostering a radical change in order to build up a sustainable road transport before fossil fuel prices are disruptively high.

To sum up, the framework gives evidence that a mix of different instruments would help to support the transition process and that a risk of under-investment into a transition strategy exists, resulting in a sub-optimal transition state of sustainable road transportation. However, further empirical and modeling research, measuring the effect of an emerging social norm on the adoption process and the willingness to pay as well as into the effectiveness of specific policy packages, are indicated. Also, it seems to be helpful to identify and further investigate the main time constants determining the technology transition process either on the user or supply side.

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