Understanding structural barriers of innovations towards sustainable transportation

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Abstract:

Congestion, pollution, greenhouse gas emissions, scarcity of oil, growing last mile inefficiency in increasing city's density, growing transport demand are major challenges of road transport towards the goal of sustainable transport. Innovation policy in transportation is the key concept to achieve this goal. However considering past measures such as in the frame of shift to rail or electric mobility we can say that targets are not achieved as expected. Hence, some barriers of innovations towards sustainable transport are not reflected. This article elaborates structural barriers of innovations which are a cage of innovation activities towards sustainable transport. The analysis is based on the concept of transport system's evolution (CTSE) – a micro-foundation of the multi-level perspective specified for transportation by the inclusion of innovation knowledge, industrial economics and empirical findings.

Three systemic features create a cage for sustainable innovations: the path-interdependency of industry regimes, the level of product innovation competition in a changing market environment and the dilemma of the internalization of social benefits into individual strategies. Policy has a key role to overcome these barriers. The article finally reflects arguments for successful innovation policy in transportation towards sustainable transportation.

Keywords*: Evolutionary economics, Evolution of transport systems, transportation future, sustainable transportation*

1. Innovation policy in transportation: what is the problem today?

Every physical social and economic interaction is realized by transport systems which have therefore to be efficient. Several transformations of transport systems took place when a transport system has limited efficient social and economic interaction, for example, the transition from inland navigation to rail and the transition rail to road. Today road transportation is the dominant form of mobility for social and economic interaction. Considering congestion, pollution, greenhouse gas emissions, scarcity of oil, growing last mile inefficiency in increasing city's density, growing transport demand and other challenges of road transport mobility, we can say that these challenges express growing inefficiency of the transport system. Hence, policy and industry are under pressure to address these challenges towards sustainable transport.

To exploit innovation potential is the key concept against this pressure. In neo-classic economic thinking innovation is understood as progress in productivity resp. efficiency and foremost a question technological progress. Companies in a market are requested to realize technical progress in competition. In the case, where challenges are related to social benefits resp. losses and external costs, such as pollution, greenhouse gas emissions the state ignites innovation activities by innovation policy measures. Innovation policy then intents to achieve two general goals: (i) it brings innovation into the market addressing challenges of overall interests and (ii) this innovation activity brings dynamic in markets and growth. "Technological progress is the basis for the future of European transport, not least in order to keep the European transport industry at the forefront of global competition. It is also the key to reducing the CO2 emissions caused by transport, as innovation and progress contribute to increasing efficiency - for example in aircraft and car engines or by replacing oil-based energy sources." (European Union, 2014) The theoretical mind behind real innovation policy in transportation is mainly based on three issues: The first is clusters of knowledge, competition and lead market conditions mainly influenced by the authors Porter (1990) and Beise (2004). The second is the national innovation system configured by private, public and semi-public resp. semi-private institutions that participate and interplay in knowledge creation, sharing and commercialization, a research field opened by Lundvall (1988). The third addresses the role of the state and financial issues of R&D and innovations in example for small "versus" big enterprises, the "funding gap" and public financing "versus" venture capital such as addressed for example by Hall and Lerner (2010) and Mazzucato (2013).

However, public efforts towards, for example, electric mobility or shift to rail were not as successful as expected. Let's consider the case of electric mobility in Germany. Between 2009 and 2015, a total of around 1.5 billion euros was publicly invested in electro mobility. The efforts sound great, but the result is: 19,000 electric

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vehicles are registered in Germany in 2015 (Frenzel et al. 2016) and by further public investments that are nearly 54,000 in 2017 (excluding hybrid vehicles, KBA 2018). The share of registered electric vehicles is less than 0.1% in Germany and far away from its 2008th political goal of one million vehicles in 2020. We can furthermore use the example of public efforts to shift demand from road to rail to emphasize challenges of innovation policy. Billions of euros over decades are invested, in innovation, infrastructure, and subsidies. However rail`s modal split could be stabilized in best case in European countries between 1990 and 2013 (Austria is the only exception in the EU, see Eurostat 2015, own calculation). Contrary, automation of transportation and mobility as a service (MaaS) seem to be promising innovations towards sustainable transportation. Here in recent years much progress of private and public efforts can be reflected. Nevertheless, to realize a fully automated road transport systems (in cities) remains a challenging task, for industry, policy, user, infrastructural, ethical/cultural etc. We can postulate that there is a gap in understanding barriers of innovation in transportation sector for effective public innovation policy.

Against this background, this paper elaborates structural barriers of innovations in transportation. This includes knowledge about the strategies of actors, the interdependencies between pressure and actor's behavior and bifurcations for future. Our perspective is the transport system's evolution (CTSE) which is rooted in evolutionary economic school.

In the next section the CTSE is described to provide the theoretic base of the following analyses. The first analysis is addressing to explain the dynamics in transportation today: the dynamics in the overall landscape, in the mass market and in niche market. The second analysis highlights structural barriers of innovations towards sustainable transport. The closing of the paper occurs with concluding remarks for implications of innovation policy in transportation.

2. The logic and systematics of the evolution of transport systems

The term "evolution" is primarily used for the development of life forms in biology. Biological evolution takes place through variation, mutation and selection. The analogy to technological evolution and the use of the term in economics and social science is that endless processes of change are described, which also take place through variation, selection and mutation. This change is driven by innovations, which in turn are continuously exposed to market development processes. The framework conditions themselves also change - through exogenous developments, but also through the development of technology and organizational forms. Evolutionary approaches were therefore developed in the so-called evolutionary economy, in which innovations play a key role in technological and economic evolution (Fagerberg 2003). The difference between an evolutionary economic perspective and a neoclassical economic perspective, which today corresponds to the standard perspective, can be illustrated best by an example.

The first cars and trucks by 1900 could not compete with the dominant railways at that time, neither technically nor economically. Analyzing the shift of market equilibriums and deducing welfare effects would be a meaningless undertaking – the cars just appeared in a niche and their costs were far away from being in balance with the benefits. From an economic policy point of view, it would not have been worth to promote the 'horseless carriages' but efficiency improvements of railways – what happened for example by electrification of railways. Nonetheless, the 'horseless carriages' competed effectively with railways only two decade later, and they became the dominant transport system in the after following decades. Structural elements around the vehicle i.e. production, supply industries, infrastructure, service networks, legal framework, markets and culture of usage have been steadily developed and characterized the overall socio-economic paradigm until today. The transport system evolved over time and brought a new level of efficiency and welfare. Cars and trucks were systematically underestimated and the potential of technological progress for rail were overrated. Could we travel back to year 1900 we surely would recommend to policy makers to promote the car and truck and not railways to establish a lead market and to realize efficient transport. We cannot travel back, but we can learn from the past. It is thus valuable to complement (neo-)classical analytical methods by alternative approaches to make such phenomenon explainable and to provide a better founded decision support for industry and policy makers.

Hence, Müller and Liedtke (2017a, b) developed an approach explaining the logic and systematic of the evolution of transport systems. The approach is a micro-foundation of the multi-level perspective (Geels 2002) specified for transportation by the inclusion of innovation knowledge, industrial economics and empirical findings. The concept covers three aspects of transport system's evolution: firstly, the evolution of transport regime, secondly, the mutual interdependency of transport regimes in their evolution, and thirdly, the interaction between the transport regimes' evolution with the socio-economic landscape.

THE EVOLUTION OF A TRANSPORT SYSTEM

Müller and Liedtke (2017a, b) distinguish four phases in the evolution of a transport system,: 1) phase of the stabilization of a disruptive technology, 2) phase of technology transition, 3) growth' phase and 4) phase of the degeneration. These four phases are characterized as follows:

Evolutionary phase 1 - the stabilization of a disruptive technology: In the first evolutionary phase, inventors and entrepreneurs try to launch disruptive technologies in the search for suitable - mainly technological - solutions to current challenges in real market application; e.g. the need of a transport system for mass goods during the ongoing industrial revolution in the beginning of the 19^{th} century led to the invention of the railway system. Typically, this is a process of trial and error: the technology is tested in market niches were new solutions are urgently needed. Once a technology design fits successfully to users' needs, the techno-organizational configuration is locked-in (Cowan 1996, Pierson 2000, Sydow et al. 2009). The phase of the stabilization of technology describes the way into the lock-in. The lock-in implies a path dependency and a path-interdependency in future; the actors do not change the basic functionality in future but incrementally refine the technology (Cowan 1996). We can state that each transport system as it is known today is based on a disruptive new technology. For example, rail is based on steam-powered carriages on iron tracks and was disruptive to horse carriages. Automobiles, as a second example, were no longer limited to the use of tracks – that was disruptive to the rail technology. The invention of the technology itself occurred always decades before it has become economically relevant in any way.

Evolutionary phase 2 - the technology transition: The technology transition describes the replacement of one technology regime by a new one. A technology regime is the alignment of actors, rules, and behavior in the sphere of a technology such as the supply industry, policy, science, infrastructure, markets, and culture of usage (Geels 2002). In this phase the new transport system (stabilized in phase 1) serves a growing demand from the niche market and can exploit the so called attacker's advantage (Christensen and Rosenbloom 1995). This effect is a composition of a) the existence of unsatisfied but growing demand, b) the innovation pathway of the regime is unable to serve this demand or has to be drastically re-aligned by the regime members to serve it and, most important, c) the capacity of improvement of the new technology is drastically underrated while the potential improvement of the established technology is drastically overrated by the dominant regime. This is explainable with the law of diminishing marginal improvements: the established technology is optimized since decades and the outcome of improvement by capital input (capital as financial and knowledge) becomes lower and lower with increasing degree of optimization. In contrast, the new technology is at the beginning of this development. Thus, when expectations of future growth will concentrate on the new technology, the capital (financial and human capital) is shifting to this technology as well. The new technology will be vastly improved by capital input and the technology transition takes place.

Evolutionary phase 3 - the growth of a transport system: After the technology transition, the social and economic orientation is focused on the new technology in a slow socio-economic restructuring process. More and more deployment fields are explored in a creative fashion, and over time, the new dominant technology is creating its own demand. For example, the rising demand for leisure and holiday trips is car-technology specific demand. As a second example, logistics services evolved as a truck-technology specific demand. A regime constitutes and fixes its structural path interdependency i.e. value chains, infrastructures, political networks, science, markets, user preferences and cultural integration and establishes a dominant technology regime (see Geels 2007). Christensen (1997a) has postulated a product competition towards a regime-conform technology development pathway on 1) product functionality (basically done during the second two evolutionary phases) 2) product reliability 3) product convenience and 4) the product price. Normally, alternative pathways will be excluded from this product innovation competition because they would destabilize the market, the market position, the profits, and patents etc. – at least the regime's economic base. Thus, the dominant technology regime tends to intensify improvement innovation resulting in an overshot of demand needs. At this point, a disharmony between a over-engineered technology and actual demand requirements emerges. The pattern of product competition and the inability to include disruptive innovations in the development pathway characterize the so called Innovator's Dilemma, which brings established firms to fail (Christensen (1997b).

Evolutionary phase 4 - the degeneration of a transport system: At the beginning of this phase, the developed demand can be satisfied by the transport system. However, the demand is saturated and the technology was thoroughly optimized within the growth phase. According to the innovation competition pattern, a price competition starts. Prices go down to marginal costs; companies will leave the market (or form cartels). Low or negative profit margins in a saturated, non-growing market impede innovation activities because the risk, that an investment will return profits, is very high. But, without innovation, the market is losing in dynamics and a spiral downwards is unleashed: no expectation for a market growth means no return on investment and thus no innovation activity and, in turn, no innovation activity means no further market growth. Mensch (1975) labeled such a situation as "Stalemate in Technology" which implies a degeneration of markets. According to Mensch, the stalemate is only conquerable by disruptive new technologies. Such technologies offer new productivity levels, new user groups and deployment areas and thus, new growth expectation leading to innovation activities (see phase 1). If no disruptive technology enters the market place, the transport system either disappears from the market by market forces (such as horse driven tramways) or degenerates to a niche market (such as horse driven carriages as the dominant urban transport system in 19th century nowadays only used for tourism or sports). Alternatively to the diminishing of a transport system, the status can be subsidized by the state (such as for freight rail services in Europe).

THE MUTUAL INTERDEPENDENCY OF TRANSPORT SYSTEM'S EVOLUTION

The described four phases of evolution characterize the pathway of each transport system. However, transport systems in a market such as continental freight services are always in an offset of phases. Because of the described theoretical effects of each phase (Lock-in, Attacker's Advantage, Innovator's Dilemma, Stalemate in Technology), the conditions for each transport systems interact with the conditions for other transport systems in form of a systematic phase shift. Thus, the rise and fall of transport system regimes is interdependent and follows a systematic self-stabilizing pattern. According to Müller and Liedtke (2017a, b) the systematic interactions between phases takes place in following constellations:

The phase of growth of the dominant transport system and the stabilization of another: The growth of a transport system is focused on the core user of the mass market supplied by the functionality of the transport system. However, this growth opens market niches. These are markets were other functionalities are required, which cannot be supplied by the mass market technology. Due to the difference in functionality niche market requirements cannot be served by mass market producers and its product innovation pattern. Towards the lock-in, new players with disruptive technologies discover this demand and ways to serve it. For example, rail is dependent on tracks and cannot or can very hardly serve the space which is not covered directly by the tracks. This market niche was covered by cars and trucks. Niches for radical new transport systems are thus systematically created by the mass market technology's characteristics and the mass market growth.

The phase of technology transition of a disruptive transport system and the phase of degeneration of another: When the technology is throughout optimized, the marginal improvements by additional capital investments decrease. However, new demand from niches arises, and the marginal profits of innovations are quite high. The dominant regime now competes with the niches by playing their market power and using political networks. Because of the facts that (i) the marginal profits are higher for the disruptive technology than for the dominant one, (ii) the growing niches cannot be served by the functionality of the dominant technology and (iii) the innovator's dilemma of the dominant regime, the attacker's advantage for the new technology inevitable leads to the technology transition. Thus, by the successful diffusion of a new technology from a niche market to a mass market, the former mass market technology is pushed into its degeneration phase. An example is the degeneration of rail with the success of the car.

The phase of degeneration of a transport system and the stabilization of another: In the degeneration phase, a technology is inevitable in a stalemate. In this situation, the technology would either be subject to market-correcting forces or it will be protected though political measures. In the latter case, the stalemate situation would continue. It is generally believed, that the only way out of this situation is a disruptive innovation. Potential innovations can be found in niches, with frequent attempts to improve a transport system - from its growth phase and more recent inventions. This offset of phases is thus a special case because it is the degeneration remains until a disruptive technology is applied as a game changer.

THE INTERACTION BETWEEN THE TRANSPORT SYSTEM'S EVOLUTION WITH THE OVERALL LANDSCAPE

According to the multi-level perspective, the landscape plays a major role for technology transitions. The landscape describes deep structural trends such as economic development, social paradigm or wars. These trends put pressure on the regime (slowly or sometimes spontaneously) and result in the requirement for a dominant technology regime adapting to the pressure. Geels (2014) distinguished in the Triple Embedded Framework (TEF) between socio-political and techno-economic pressure on a technology regime. However, the socio-political and techno-economic pressures have a different meaning for a technology regime and its innovation pathway.

The techno-economic pressure can be related to disruptive innovations implying a new paradigm. Such innovations change amongst others the labor skill profiles, demand pattern, the competitive base for company's products and production methods, and the growth of new market players (Freeman and Perez 1988). Such innovations were, for instance, the steam driven spinning machine (industry sector), railways (transport sector), electricity (energy sector), motorized vehicles (transport sector), and information and communication technologies (telecommunication sector). Disruptive innovations are game changers – their effects on the landscape are tremendous and thus, the influence of disruptive innovations outside the transport sector put of pressure on the transport system to adapt. A transport regime can adapt to such techno-economic pressure in following ways: Firstly, such transportation-external disruptive innovations provide new input factors. Hence, the efficiency of production methods can be enhanced. Secondly, such innovations define the new paradigm of the society and economy and thus, also the orientation of the transport mass market needs. The incentive to be in line with this paradigm resp. the changing demand is inherent for the transport regime's business. Thirdly, after 40/50 years of economic upswing (related to a duration of a Kondratieff) of one transport regime, the situation often ended up in an economic crisis and its downswing. For instance, the worldwide automotive industry experienced a first downswing in the 1980s with a deep crisis for American and European producers. Aligning the products with the new technology and its economic upswing, is a way to be part of the growth as it was the case for the car industry with the availability of capable information and communication technologies (Kondratieff since the 1980th). It will be integrated most likely in the competition on reliability and convenience. The pattern of integration corresponds to the Reverse Product Cycle (RPC, Barras, 1986) because the transport sector is then a user of external technologies. The RPC says that first the new technology will be applied to improve the efficiency of the existing, secondly quality improvements are addressed and at least new products will be developed by the external technology.

The socio-political pressure rises by the growing negative impacts of a technology and the technology's inability to solve it. For example pollution, noise and congestion are congruent with the success of cars and trucks. However, in contrast to the incentive to address techno-economic pressure in the incremental pathway of a transport regime, it is rather unattractive in the case of socio-political pressure. The reason is firstly, the free rider problem. To address social benefits in a single company's innovation strategy brings no return on investment. Rather, other companies would benefit from incremental improvements without investment and risk. Moreover, secondly, it would need a radical change of the incremental innovation pathway, because if the incremental pathway would address it, it would not have become a pressure. It thus would need a breakthrough of the lock-in of firms and other regime elements. This is related to risk, sunk costs and new, uncertainty investments. Thirdly, the pressure increases from a niche to a mass pressure (for example; environmental issues of the car in the 70th), however do not represent the core market resp. the served mass market of a regime as part of the regime by definition. The incentive for risky investments and failure for a relatively small niche demand is very low. Fourthly, the existing power of the network since policies and its users are also part of the regime making the industry regime belief in a successful fight against pressure by campaigns, influence of laws and market rules. Because of these reasons it is unlikely to address socio-economic pressure but likely to address techno-economic pressure for a transport regime. Instead, according to the TEF (Geels 2014) four stages characterize the cope of the pressure: 1) Denial of the problem, 2) local search for solutions, 3) distant search for solutions and 4) path re-creation with a solution. The fourth stage is unlikely as argued above.

3. Insights in the dynamism of today's transportation

The CTSE distinguishes between two types of pressure, which are diametrical for the behavior of the regime and the consequences. The socio-political pressure arises essentially from the mass effects of the dominant regime and thus challenges the techno-organizational configuration of the transport system. The acceptance of solutions against the pressure is therefore not attractive for the regime. The techno-economic pressure arises essentially from new basic innovations that on the one hand increase the relative efficiency of society and economy, but on the other hand also imply a new socio-economic paradigm (Kondratieff cycle). Because the efficiency of the dominant regime can increase and the competence of the regime can be improved through basic innovation, it is attractive for the regime to integrate it into the innovation path. Against this background, the current status and behavior of the automotive regime in the face of socio-political and techno-economic pressures can be characterized as follows.

The techno-economic pressure on the automotive regime results from the current digitalization-Kondratieff. Computers, Internet and Co. created a new paradigm of social and economic development. As a result, competencies in automotive engineering from the information technology sector are essential for vehicle dynamics, engine control, comfort functions, networking and entertainment. It is in fact impossible to imagine the automotive industry without them. The CTSE presented the Reverse Product Cycle for the model of integration of the basic information technology (IT) innovations. IT was first introduced in the 1980s in the automotive industry to increase the efficiency of existing products and their production methods. Japanese automotive production was a pioneer in automation and thus achieved such efficiency advantages that the

American and European automotive industries in particular were in crisis. Within a few years production was automated there too, e.g. at Volkswagen in 1986 the body production was automated by 80%, in 1986 40% of the painting was automated and in 1986 25% of the final assembly was automated (Hessler 2014). Due to the CAN bus in vehicles, which was also established in the 1980s, product efficiency was increasingly controlled by IT rather than mechanically. In the 1990s and especially after the millennium, the use of IT in automotive engineering concentrated on increasing the quality of products. For example, active safety systems have been integrated into the innovation path ("The safest car in the world") and finally more and more comfort functions (automatic light, windscreen wiper and boot lid, remote car keys, etc.) have been integrated by IT sensors. Also the entertainment systems in cars today, the connectivity to smartphones, navigation systems etc. which are nowadays standard for new cars, so to speak, serve to increase the quality of the product. There are currently two major efforts for the future in the automotive world that can undoubtedly be interpreted as new products: firstly, automated driving and secondly, mobility as a service (MaaS). "With digitization, we are now facing a historic mobility revolution: automated and networked driving. Mobility is thus taking on a completely new dimension, developing into "Mobility 4.0". (BMVI 2015). The further integration of IT into the regime is actively promoted by the regime, industry and politics. It is not only attractive for the association of the German automotive industry (VDA), but this path of innovation is also praised as a solution for socio-political pressure: "Today's mobility systems face many challenges: Globalization and urbanization are rapidly increasing the volume of traffic and could push transport systems to their capacity limits. By 2050, 70 percent of all people will already be living in cities. The number of automobiles will double. Automation and networking, however, offer the opportunity to successfully master these global challenges because they make driving more efficient, safer and more environmentally friendly. German manufacturers and suppliers want to further expand their innovation leadership in automated and networked driving.” (VDA 2016)

However, the other solutions for meeting the increasing socio-political pressures such as congestion, emissions, noise etc. are not attractive for the automotive regime, should be explained to the Triple Embeddedness Framework (TEF) according to the CTSE. A regime follows the TEF pattern 1) Denial, 2) Local Search, 3) Distant Search and 4) path recreation. We evaluated the yearly reports of the VDA from 1961 to 2016 (VDA, several years) on statements and arguments concerning environmental issues. We found a clear pattern in line with Geel’s triple embeddedness framework:

1. Denial: arguments that the “problem is not existent”, “others are worse”, “alternatives do not appropriately contribute”, the “problem can be solved by policy” and so on were put forward until the 1990th.
2. Local search from ca. 1990-2010: arguments that “the industry has made a lot of effort, more than others”, “high investment have been made to solve the problems”, “high contributions and achievements in the traditional technology”, “incorporation of selected alternatives”, “trials with alternatives but not as sufficient than traditional technologies” could be found in response to environmental issues.
3. Distant search starting from ca. 2010: triggered, for example, by government promotion of electric mobility arguments, “we are trying alternatives”, “proposals for alternatives”, “assessment of alternatives”, “achievements and potentials of traditional technology pathway”, “announcement of the enlargement of the product portfolio” are published in the reports.
4. Path re-creation: a clear commitment to green mobility in its full extent is still outstanding – in fact there are no signs of that.

Although more than a billion Euro of public funds have been invested in adapting the pathway of the automotive industry (to promote electric mobility), the change in the technical-organizational configuration is very weak and on a low level. This holds true in industry, in politics and among most users. But because solutions are needed, DHL, formerly users of light commercial vehicles, for example, are becoming producers of electric vehicles. Also UPS as a user started to experiment with hydrogen trucks in their logistics fulfillment. In some cities, such as Paris or London, clear deadlines for internal combustion vehicles were introduced and electric mobility is strongly driven by a newcomer to the market (namely Tesla). These are signs of the regime's destabilization.

Overall, while the regime is still in the growth phase of making profits and the mass market is still growing, limits to growth are becoming more obvious as has been shown. The hitherto overlooked problem of the regime, however, lies in its own innovation path, which is obviously being driven forward with automation and MaaS. IT is used to further increase comfort and convenience. In a nutshell, automation reduces the driver's driving time and MaaS reduces the access threshold to the car to a minimum. In the CTSE, Christensen's Innovator's dilemma is used for this process. According to this, competition for convenience makes the products homogeneous in all their properties (functionality, reliability, convenience) and can therefore only be discriminated against by the price. In the special case of the truck market, price competition was already suspended by the cartelization of

European manufacturers at the end of the 1990s (EC 2016). Following the ruling, we can now expect Bertrand competition in this market.

According to the CTSE, the regime's growth phase creates a systematic niche that cannot be served by the regime, or only poorly. In this niche radical innovations try to stabilize (correspondence of the growth phase and the stabilization phase). Because it was shown above that the growth phase of today's dominant automotive regime is already advanced, a systematic niche should already be recognizable. Socio-political and techno-economic pressures are making new demands on transport systems: they must be on-demand, time-space instant and ecologic. While automated mobility services can partially meet these requirements (they are on-demand), they do not become ecological per se and not time-space instant at all. On the contrary, the limit of time-space instant is the capacity of the infrastructure or the congestion. Automated MaaS reduces the generalized costs and thus, according to the Law of Demand, the demand for transport will continue to rise in the future. However, average speeds in cities are already low and the infrastructure is congested. If demand continues to increase, this becomes the limit of growth. The techno-organizational configuration of the automobile cannot therefore serve this niche. This niche is already particularly evident in the parcels market. This is growing at double-digit rates worldwide each year and is driven by e-commerce. For delivery this has the following consequences (restrictions): 1) shipment sizes decrease, resulting in more parcel drops and pickups per tour. For example, in the B2B sector expensive store space for stock is optimized, meaning shops require deliveries a couple of times per day. 2) A growing number of parcels need to be delivered within a smaller time window, consequently increasing the number of delivery staff. That means more vehicles are needed for the same number of parcels. 3) Online retailers offer instant delivery within 60 to 90 minutes after finalizing an online order. This implies either disruptions in tour organization or vehicle deployment dedicated for instant tours.

However, because the niche has been growing significantly for years, it is also particularly attractive for investments. Specifically, investments are being made in innovations that can meet the growing market demand. Today, radical innovations are trying to stabilize themselves in the niche of on-demand, time-space instant and ecologic transportation. Two examples are particularly prominent: firstly, they are air drones that are designed in the parcel market but also for passenger transport. Their application potential and thus efficiency potential even goes beyond the transport market: agriculture management, monitoring and inspections are examples of this (Nesta and Innovation UK (2017). The other prominent example of radical innovation in this niche is the Hyperloop for passenger and freight transport. One of the investors in Hyperloop said for the Hyperloop cargo: "The global growth of e-commerce is driving a dramatic shift in both consumer and business behavior. On-demand deliveries are a novelty today. Tomorrow it will be the expectation." (Branson 2018) The niche exists, the main question resulting in the coming decades is: who can serve it best, and with what technology?

And rail? For railways we can postulate a stalemate in technology since the transition from rail to automotive took place. The overall landscape is shaped by automotive since than resulting in a new socio-economic paradigm: new input factors, new companies and sector orientation, new market rules, new demand patterns for goods and services, new infrastructural configuration etc. (see Freeman and Perez 1988). Thus the market is saturated and degenerating because the core competence of railways, mass product distribution and collective passenger transport is losing of relevance compared with the growth of road transport demand.

The findings from the CTSE suggest the following development path: Firstly, automation, electrification and MaaS describe the future pathway of the road regime. This intensification is based on the established system. If these developments are fostered, it is very likely that we will have such an intensified road transport system in the next decade and beyond. Secondly, we can expect that a new transport system will provide a disruptive efficiency gain in the upcoming decades when the established road based systems will reach their ultimate growth limit. This disruptive new transport system is currently in the stabilization phase. It could be a Hyperloop, airborne drones or maybe other inventions. Entrepreneurs and inventors figure out niche demand specifications and corresponding techno-organizational concepts to serve it. Once the stabilization completed the winning concept will allow for the advantage of the attacker and the transition. The increase in efficiency for society and the economy will set a new Kondratieff cycle in motion. Thirdly, after a transition, the road regime will be pushed into its degeneration phase and thus, into a stalemate in technology (as it is true for rail and inland navigation since decades). It than needs a revolution of the market offer.

To emphasis, it is not the similarity of the situation compared to 100years ago and beyond. It is the systematics of the situation: In a time perspective, starting at ca. 1800, we can see the pattern along inland navigation, rail and road. For future, the stabilization of disruptive innovations becomes very likely (see Figure 1).

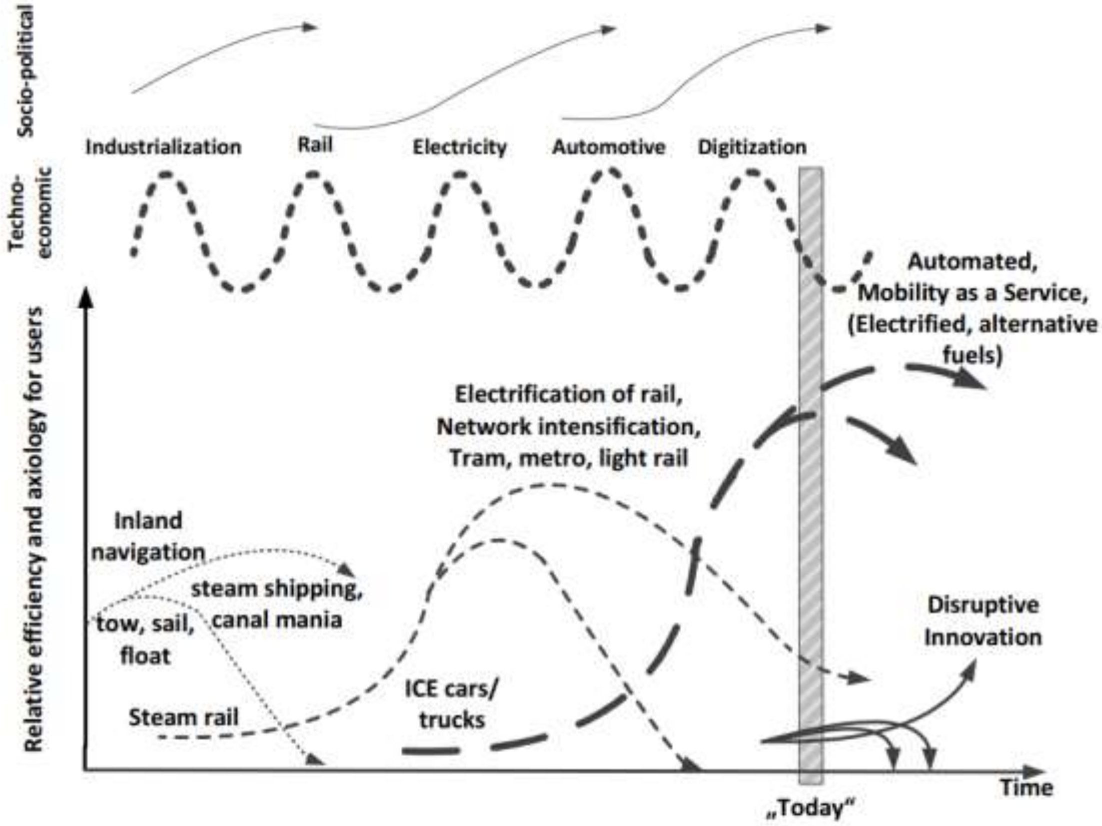

Figure 1: The systematics of the co-evolution of transport systems in a time perspective

In summary, it can be said that the automotive regime is increasingly under pressure from socio-political and techno-economic developments. It has been shown that socio-political pressure has so far been insufficiently integrated into the regime's development path. Rather, the regime focuses on the integration of solutions for techno-economic pressure. Overall, however, the regime's growth phase is well advanced so that it is approaching the threshold of homogenous goods and price competition (on the truck market, this has already occurred). The intensifying innovator's dilemma has already led to a systematic niche that is currently experiencing enormous growth: on-demand, time-space instant and ecologic transportation. We thus can reflect, that transport systems have different evolutionary phases which imply specific barriers of innovations.

4. Major barriers of innovations towards sustainable transportation

The introduction of this paper addresses that barriers of innovations resp. approaches to overcome barriers are formulated in cluster-policies towards lead markets (to utilize the power of knowledge concentration and knowledge competition in a specific innovation field), national innovation systems towards institutional interplay (to realize a knowledge flow, innovation-specific role on institutional level from basic invention to commercialization), and the governance of capitalization of innovation efforts as investments. We now add structural barriers of innovation activities to these from the perspective on transport system's evolution and based on the theories provided inside the CTSE. The structural barriers of innovations are not referred to evolutionary phases of transport systems as it might be expected from the previous chapter but are described as structural barriers towards sustainability were each existing mode plays a role for this target. The aim is to provide a general understanding of structural innovation barriers in transportation.

THE PATH INTERDEPENDENCY OF INDUSTRY REGIMES

Knowledge created in the field of innovation studies revealed that technology is not separated from social, economic, cultural and political context. The term socio-technical regime expresses that a co-evolution and alignment of activities exists. A regime is configured by technology, industry, supplier, infrastructure, law, policy, user behavior, and culture. It is the systemic, socio-technical regime character of large technical systems, such as transportation systems, which creates quasi-stability. This implies that regime elements can hardly be changed by disruptive steps but only incrementally – in co-evolution and alignment of the regime elements. This further implies that disruptive innovation steps are destabilizing a regime, because disrupting one or two elements disconnects the others to this development.

Let's consider automated driving as an example: Technically, automated driving is realized. Further learning is needed to eliminate teething troubles in technology however; many tests of automated cars in public space could be successfully achieved. The point is now, those other regime elements such as infrastructure, traffic rules, laws/regulations, ethics, the culture of car driving (meaning also mixed traffic of automated and human driven cars), market rules (e.g. car ownership, assurance) etc. are developed 100 years along human driven cars. They have to be taken into account with the development stream and the co-evolution with the technological potential of automation. To be clear, it is not impossible but it is a greater challenge than purely to engineer the automation technology.

THE PRODUCT INNOVATION COMPETITION PATTERN IN A CHANGING MARKET ENVIRONMENT

Disruptive innovations, such as the horseless carriage (the car) in its period of birth are new to the world in each aspect: technology, industry, supplier, infrastructure, law, policy, user behavior, and culture. Hence, the creation of a regime begins at level zero in these aspects by plenty innovation steps. In a long term perspective however, an innovation pattern is found how the industry around the technology is competing. This pattern begins with the "definition" of the functionality and leads in the competition to homogenous goods in functionality (a car has four wheels, four seats, a steering wheel, a roof, light, wiper, the engine in the front, a trunk is rear etc. what took around 40 years to find that). After achieving homogenous goods in functionality, the industry competes in reliability. In the competition products become homogenous in functionality and reliability. After, the products are differentiated by their convenience for users. If products are homogenous in functionality, reliability and convenience in the course of competition, users will decide by the product price. At this stage, three implications come true: The first is that during the product innovation competition the complexity of the regime elements increased tremendously. The optimization level is very high what means that marginal improvements of innovations become smaller, but investments for these improvements increase (law of diminishing marginal gains). An example of it is that it was more rapid and cheaper to improve the motor of a car in the, for example, 60th than it is today. The second is that in the price competition the market becomes saturated because it lacks in real innovations and hence, replacement purchases are the main driver to buy a new product. Thirdly, in a prize driven market no or very low margins can be achieved (Bertrand competition). This means that there is a lack of profitability of investments and thus of capital for reinvestments in innovations. This situation can be labeled as stalemate in technology: no increasing demand and low profitability implies no incentive (ability) for innovation investments – no innovation investments imply no market dynamic, no increasing demand and hence no increasing profitability. It is an economically spiral downwards.

An example of this situation is freight railways, were it needs public money to innovate anyway because of no margins and only minor (if any) growth of the market. Another example in an earlier phase of this process is the European trucking market. Here the manufacturers had already formed a price fixing cartel at the end of the 1990th to suspend price competition for homogeneous goods. After the cartel became known strong price competition can now be expected and possible innovations will be more difficult (AdBlue collusion and other environmental innovations).

THE DILEMMA OF SOCIAL BENEFITS AND EXTERNAL COSTS IN INDIVIDUAL STRATEGIES

Congestion, pollution, greenhouse gas emissions, oil consumption etc. are external costs and hence these are social losses. To tackle them in the innovation pathway of an industry regime would lead to social benefits. However, it is not attractive to include social benefits in a company's innovation pathway resp. in an aligned form in the industry regime. Such innovations are thus impeded and hindered. The reasons for that are explained following.

The first point to understand is that the source of external costs lays in the regime's core and its innovation pathway. It is the mass effect of the developed functionality (internal combustion engine), rules (traffic rules, emissions standards) and co-alignment (city structure, just in time production): Car by car, truck by truck. If external costs become a pressure (major challenge), that means that the natural innovation pathway of the regime is unable to meet this challenge. Otherwise, it would not have become a pressure. This implies necessarily the incremental natural innovation pathway of the industry regime has to be left which can be achieved by radical change resp. disruptive innovations.

Secondly, to include disruptive innovations changing the core technology and core functionality of an industry regime is linked to high risks, sunk costs and new, uncertain investments. The risk is that the mass market served by the regime is quasi-stable with regard to market shares, market rules, patent development and exploitation, margins in the mass market, user behavior etc. disruptive innovations require a change in almost everything – it will devaluate patents, knowledge, user behavior, markets and even market player (by new market entrants and market exits). There must be a willing to learn new from the beginning – with misguided investments, technology failing, learning costs. The mass market will be destabilized for a hopefully growing niche demand. Moreover, the first strategic moves towards incorporating social benefits are the most risky, most expensive and most uncertain because a suited alternative is in the beginning of being explored. That raises the free rider problem: following a first successful pathway and speed up is cheaper than being the pioneer. In economic-strategic thinking of a company within regime's collusive forces the incremental intensification of the regime pathway is much more attractive than its disruption. A regime, through its composition in industrial, political, social, infrastructural, scientific and inter-alignment members, has many power mechanisms and connections that are in harmony with the regime or the established innovation strategy - as winners in an innovation pathway. Using this power to combat socio-political counter-movements is easier (lower generalized costs) than adapting to them (see above). So power is used in networks to fight against pressure, e.g. through the influence of requirements, laws, public opinion etc.

Let's consider electric mobility and the emission standard scandal (Dieselgate) in Germany as an example of this. Germany is market leading in automotive sector. Emissions and pollution are external costs whose elimination is on the agenda of international agreements (Kyoto climate goals for example). That forces to national action – in Germany electric mobility was hence considered as the solution. Although public funding was high to include electric vehicles in Germany's automotive OEMs until today both, product portfolio and sales are on a low level. Instead of taking the chance, that public funding is sharing the risk and costs of pioneering electric mobility towards environmental sustainability, the improvement of Diesel engines were fostered (incremental intensification). The optimization degree of the Diesel engine today however don't allow great marginal improvements with manageable costs (see the implications of the advanced product innovation competition pattern explained above). Tacid collusion and cheating were cheaper, maybe necessary. However, the forces of the regime go beyond this industry problem. Until today, the Dieselgate lacks in social, legal and political clarification (see above stabilization of regime elements). Steps toward a sustainable transport system thus implies a regime dilemma.

5. Policy implications towards sustainable transportation

In the previous chapter we have outlined structural barriers of innovations towards sustainable transport, which have not been reflected in the literature yet as a cage of innovation activities. What we also have seen by the briefly described examples is that these barriers are relevant for sustainable transportation and innovation policy. The essential postulation for innovation policy in transportation towards sustainable transport is that it needs disruptive innovations because the intensification pathway of incremental improvements is the source of major challenges (car by car and truck by truck). To achieve sustainability we less have to think in incremental technical progress but rather in disruptive alternatives. We now provide implications of the findings for innovation policy towards sustainable transportation.

The state as investor: In general, there should be no great theoretical doubts; enriching transport policy with innovation policy is helpful here to give dynamism to the markets and to politically guide technological (regime) development in the transport sector which is outside the natural innovation pathway of the regime. However, the state has a key role in the innovation process. In a stalemate in technology situation or in a regime dilemma situation it needs the state to share risk and to ignite basic activities. This means that public funds or correspondingly state-subsidized loans or the like are indispensable to trigger innovation. The point is that for disruptive innovation the state is the investor when private capital is avoiding the investment or the risk is even too high for venture capital industry.

Acceptance of the transition: successful disruptive innovations will and has to dramatically change the established regime structure. That implies not only change but also Schumpeterian creative destruction of obsolete regime elements. Disruption is necessary because the incremental pathway is a deadlock. The creative part in the destruction however will improve the situation in terms of social benefits, new growth and potential of lead markets.

Growth from niches: to change a large technical system needs system innovations, along the system nearly in time for all elements. Otherwise the famous chicken-egg problem is argued. It thus needs a growth from a market niche were the disruptive new functionality is experimented and specialized on. Even cars and railways have grown out of niches. Growth out of a niche has two major advantages: firstly, the disruptive innovation can be specialized on demand requirements which are not served by the mass market (avoidance of the regime dilemma in the transition process). Secondly, only a successful niche concept, able to create a new mass market will unleash the transition process. Unable niche concepts disappear from market or will remain in a niche. This provides a quasi-guarantee that the creative destruction leads to a market compliant solution.

New actors are more relevant than incumbents: established market players can incorporate basic innovations into their production processes. To this end, there must be a willingness to grow out of the niche and to revise the market offer. This is only likely if the regime is not endangered by the basic innovation (subject of Schumpeterian destructions) and moreover, the capability of the regime is enhanced by the innovation. Especially with social benefits this is mostly not the case. Because of new players do not have existing production capacities, established customer relationships, patents etc., they are more willing to try something new. Moreover they need to try disruption to enter the established market structure (in the niche). It is therefore particularly important to attribute a high potential to new players to give impetus to the market and the regime.

Adapted framework conditions for disruptive innovations: disruptive innovations which revolutionize the previous technological basis are naturally not suitable for established production processes, standards, institutions, etc. They therefore need test fields, progressive thinking and acting authorities, ideal protection against resentment as well as capital/subsidies in order to gain access to market application. Because policy is part of the dominant regime, it needs new institutional framework (institutional bodies) to enable disruptive innovations.

The state does not seek the winner but the winner seeks the state: It makes no economic sense to centrally select a new quasi-winning technology (and this possibly even on the basis of proposals from the circle of already established market players). Many experiments and a promotion as open to techno-organizational business concepts as possible create a situation in which effective market selection takes place and a truly suitable solution, the winning technology, emerges. Even though many ideas will fail, which initially means lost public money, all failed attempts to find a winning technology help by learning from mistakes. What is also more decisive is the extent to which society would benefit from solving unsustainable transport and future lead markets.

The time component: New lead market potential lays in every young disruptive innovation: remember the first rail or cars which sounded crazy in their time of invention. In 1864 the head of the Prussian Statistical Office wrote: “By the way, who can tell us where the railways will be in 100 years, and whether they will not be completely devalued by new inventions? What would the railways be worth, if, for example, you would find the means using the steam engine on the highways to work with the same power and speed as on the railways?” (Engel 1864, literally). Ten years later, the internal combustion engine car was invented and another 30 years later automotive ignited a transition from rail to road and a general economic upswing. This makes clear that transition is a long term goal and undertaking.

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