Technological Forecasting & Social Change 92 (2015) 276–289

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Towards a regime-based typology of market evolution

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A R T I C L E   I N F O

Article history:
Received 22 August 2013
Received in revised form 1 October 2014
Accepted 3 October 2014
Available online 20 October 2014

Keywords:
Innovation typology
Market evolution
Regime
Transition
Socio-technical change
Disruptive innovation

A B S T R A C T

This paper provides a typology for the analysis of markets in which new innovations have the potential to cause *regime transition*. We elaborate the typology of transition pathways (Geels and Schot, 2007) into a typology of market evolution, with transition being one of the possible types. We strengthen the theoretic link between transition and industrial innovation studies by moving beyond the incremental-radical innovation dichotomy, adopted in many industrial innovation studies, as well as map out the socio-technical dimension of market evolution. We test the Regime Evolution Framework (REF), as we call it, against the introduction of steam power in trains and ships, which are well-established cases. By doing so, we are better prepared to adopt the framework for the analysis of electric propulsion systems in cars, a potentially disruptive innovation that has slowly been entering mainstream markets. The framework allows us to: (i) better qualify the categories of sustaining and disruptive innovation; (ii) understand the evolution of hybrid patterns of market innovation, since the elements of emerging disruptive innovations sometimes sustain the established technology, and; (iii) assess and map emerging market patterns.

1. Introduction

The classification of technological change and market innovation remains a challenge in innovation studies. Due to the large number of variables involved in the origins, causes and implications of innovation, a plethora of typologies have been suggested, such as radical versus incremental innovation and the product-process distinction (see Garcia and Calantone, 2002 for a review). Two of the most adopted taxonomies are the ones of Bower and Christensen (1995) focusing on disruptive and sustaining innovation, and Abernathy and Clark (1985) addressing architectural, market niche, regular and revolutionary innovation. Although the typologies are instrumental to discuss firm strategies, understanding why the market share of disruptive innovation may grow at the expense of the *market regime* (i.e. the 'order of an industry', in Christensen's words) requires additional analysis. A third well-known typology is the distinction of incremental, radical, technology system and techno-economic paradigm innovation (Freeman and Perez 1988), categorizing levels of innovation. Overall, these typologies organize a broad range of dimensions of innovation from (incremental/radical) product or process innovation, to technology system innovation to innovation of whole societies.[1] They do not address the evolution of markets of specific technologies.

Whereas economists and business researchers talk about markets, others have coined the notion of *regime* (Kemp, 1994; Rip and Kemp, 1998; Geels, 2002): the socio-technical system that has grown between the hardware and user perspectives and practices (reflecting their preferences and endorsed social connotations), producer capabilities, business models and production technologies, regulations, and supporting institutions. Product regimes are socio-technical *ensembles* that have been aligned and, overtime, create and re-create the conditions for their own continuation. Accordingly, socio-technical systems have gained a level of stability

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[1] As compared to Freeman and Perez' categories, our typology seeks to map out their category 'technology systems'.

http://dx.doi.org/10.1016/j.techfore.2014.10.002
0040-1625/

through economies of scale and scope, through sunk costs, and through social learning. Although alternative regimes can be contemplated, they are not easily realized because they would have to go through a process of emergent realignment during which they must compete against well-developed alternatives.

There is a need for a market evolution typology that goes beyond the distinction between incremental and radical innovation, and maps out the socio-technical dimension of market evolution. Such need becomes clearer when we seek to explain innovation trajectories, for instance, associated with the electrification of automobility. Will the future mostly be a greening of cars without much change in the social context of mobility (such as average trip length, vehicle range, vehicle social status, refuel time, prices etc.) and without much change in the hegemony of established firms, or will changes be more fundamental? Does the success of the Toyota Prius car mean that the dominant low carbon technology will be hybrid? Or does the hybridization represent only a stepping-stone towards pure electric vehicles operating in a different social context of mobility? What would this mean for established car firms? Unlike explanations focusing on the economics of different technologies, how could we map the sociotechnical dimension of the market so to better structure not only past changes in technological regimes, such as the ones that produced a new era of ships and trains in the 19th century, but also help to explore the potential of current innovations in the market?

This paper addresses this need for a market evolution typology by elaborating the typology of transition pathways (Geels and Schot, 2007) into a typology of market evolution with transition being one of the possible types. Relative to their typology, we slightly rearrange the distinction between timing and nature of innovation: regarding the nature of innovation, we follow Christensen (1997) dichotomy of disruptive versus sustaining innovation more explicitly (in Geels and Schot's it resounds implicitly). We find the timing axis of the transition pathways typology somewhat problematic because it is so relative: whether or not niche-innovations are 'fully developed' is not objective but depends on the interpretation of actor groups and may greatly differ among both firms and consumer groups (as Geels and Schot acknowledge on p. 405). Actually, this interpretive flexibility of the niche technology constitutes a large part of the explanation for whether and how the niche innovation further develops or not (Bijker, 1995).

Therefore we employ a more objective indicator - market share of the niche - as the second axis, which helps to sketch socio-technical trajectories of niche innovations in the market overtime (both regime sustaining and disruptive innovations). Furthermore, this allows highlighting the path of innovation *momentum* in the market, indicating the strongest niche in terms of market growth. We use three cases in Sections 4 and 5 to illustrate our assertions and, for each case, we are explicit about the boundaries of the market or sector under study. This is because the '*regime*' is a concept that can be applied at various levels (global market, national market, end-product market, component market, etc.), requiring the precise identification of the market or sector so to, unambiguously, identify the regime.

Our typology (as elaborated in Section 3) helps to sharpen the subcategories of sustaining versus disruptive innovation in the market: market regime reproduction or reorganization versus market regime amidst diversification and regime transition. In other words, the framework helps the analysis of the evolution of market innovation. In particular, our analysis helps to expose periods of 'hybridization' of the market. Our research cases show that existing companies may successfully hold their position against newcomers through a radical redesign of their products, transforming disruptive innovations into niches of the existing market regime. For example, the electric motor may be applied in cars in both disruptive (electric only) and sustaining (hybrid) ways. This means, as we show in this paper, that the notions sustaining and disrupting are not inherent technology qualities that can be attributed *a priori*, but depend on how the technology is applied in the product and manifests itself in the set of product features. The success of such a product is, in turn, the outcome of variation and selection processes in the market.

The paper is organized in five further sections. In the following one, we summarize the typology of Christensen and of Abernathy and Clark, making it clear that, albeit market-related, they are not tailored to understand market evolution. Section 3 presents the Regime Evolution Framework (REF), which is 'tested' in Section 4 against the assessment of two historic examples of disruptive innovations that resulted in regime evolution: the cases of steam locomotives and ships. Section 5 uses the typology to analyze more recent and inconclusive developments: the market evolution of electric propulsion systems in cars – for long considered as potentially disrupting the market. By discussing the merits of the scheme and its implications for research and practice, Section 6 leads to the conclusion of the article.

2. Innovation typologies

Among several typologies for innovation available in the field of economics and management, Durand (1992) identified four criteria for the categorization of innovation: 1) *Technological input*: the technical novelty or scientific merit; 2) *Competence throughput*: new competence requirements (resources, skills and knowledge); 3) *Perception of the market*: the market novelty, new functions proposed to customers; 4) *Strategic output*: impact on the competitive position of the firms. For example, the distinction of radical versus incremental innovation has technological novelty, the first criterion, as its root. These perspectives may help to explain the focal points of the most renowned market-related typologies of innovation – those of Abernathy and Clark (1985) and Christensen (Bower and Christensen, 1995; Christensen, 1997; Christensen and Raynor, 2003) - which contain elements of market evolution but are not (and not intended as) typologies of market evolution *per se*.

The classification of Abernathy and Clark (1985) is based on the effect of an innovation in the technological and production competences of a firm (e.g. skills, technical knowledge, supplier relations), and the effects of an innovation in the market. Innovations can conserve or disrupt existing competences (the technology dimension) or market/customer linkages (market dimension). Together, these dimensions generate four quadrants for innovation, depicted in Fig. 1. They are: (i) *Regular innovation*: conserves both existing competences and applies to existing markets and customers; (ii) *Niche creation*: conserves existing competences but disrupts user relations and applies to

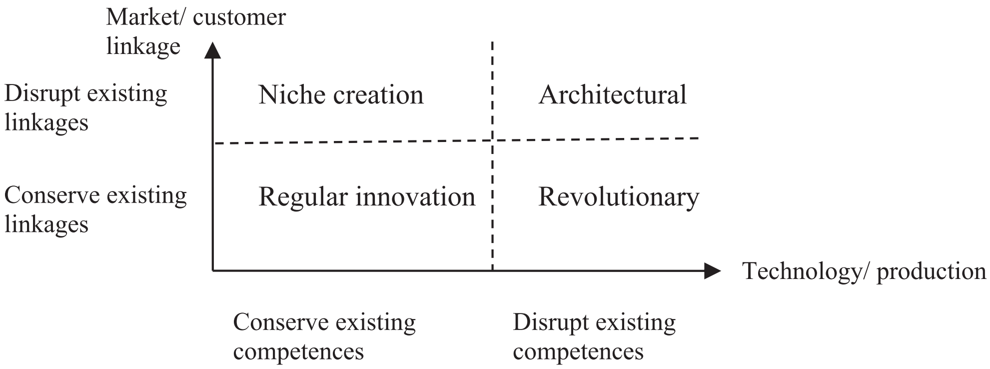

Fig. 1. Typology of innovations (Abernathy and Clark, 1985).

new markets; new markets are explored with existing products; (iii) *Revolutionary innovation*: disrupts technology competences but sustains users and institutional linkages (same markets); (iv) *architectural innovation*: disrupts both existing competences and linkages with users; creates new industries or reformulates an established one.

The classification is applied to categorize innovation efforts of a firm in order to analyze and enhance firm strategies, but it does not intend to classify market evolution trajectories. Therefore, in terms of the four underlying perspectives that Durand (1992) identifies, the classification of Abernathy and Clark has the 'strategic output' for firms as the central theme.

Christensen (1997) coined a new distinction of innovation by differentiating between sustaining and disrupting technologies. In later publications (Christensen and Raynor, 2003; Johnson et al., 2008) he replaced the term disruptive technology with disruptive innovation because he recognized that only a few technologies are intrinsically disruptive or sustaining in character; rather, it is the business model that the technology enables that creates the disruptive impact. In Christensen's typology, sustaining innovations are novelties fostering improved product performance. He argues that most new technologies fall into this category. Some sustaining technologies can be discontinuous in character but mostly are of incremental nature. What all sustaining innovations have in common is the capacity to improve the performance of established products that mainstream customers have historically valued. An example is the innovation of electronic fuel injection, introduced in the automobile market in the 1980s, which improved the fuel efficiency of internal combustion engines but did not disrupt the market for cars.

Disruptive innovations, on the other hand, are innovations that, initially, in the eyes of mainstream customers, typically perform worse on some key functions (Christensen, 1997: xviii), but they bring to the market a very different value proposition than had been available previously. Generally, their lower price or unique features are attractive for a share of existing or new customers. An example is the photography market after 2000. Early digital cameras suffered from low picture quality and resolution and long shutter lag, but the convenience of small memory cards and portable hard drives that hold thousands of pictures made them attractive for some consumers. Economies of scale and dedicated R&D resulted in cheaper and better products, which helped them to reach a wide consumer base. As a result, non-digital cameras were transformed into a niche product.

In many cases, the disruptive technology accelerated the leading firms' failure. Christensen (1997) gives the example of the disk drive market in the 1990s, in which oxide disks started to reach a physical limit (in terms of bytes of information contained) and IBM, Control Data and other incumbents invested more than $50 million developing thin-film coatings. Other companies embarked on new technologies, mostly based on architectural innovations that shrunk the size of the drives, from 14-inch diameter disks to 8′, 5.25′ and 3.5′, and then from 2.5′ to 1.8′. Ultimately, the challengers won the battle (Christensen, 1997).

In later publications, Christensen made a distinction between two types of disruptive innovations: new-market innovations and low-end market innovations. Low-end market innovations are those that result in worse product performance; they serve users who are attracted by low prices. An example of a low-end innovation is cheap retailing by megastores like Wal-Mart. On the other hand, new market innovations are those serving new users. The personal computer is an example, since new customers had not owned or used the previous generation of products (Johnson et al., 2008).

Disruptive innovations bring to the market a different value proposition to established mainstream markets. With time, lower quality may change into superior quality. This is what happened in the case of the disk industry, super store retailers, and digital camera technology. The new disks were able to store more information; the large retailers offered more choice and offered to take-back products within a certain period; digital cameras offered functionalities that could not be provided by chemical photography such as the possibility to store it on a computer, obtain a preprint view, and manipulate the image. A more recent example is downloadable digital media disrupting the market of CDs and DVDs.

Christensen does refer to market evolution in various ways, but the analysis and the consequent recommendations are kept at the firm level, since his interest is on how companies (should) behave when confronted with disruptive innovation. Although his analysis addresses the dynamic nature of product performance and firm strategies, he does not assess how the evolution of the market share of the disruptive innovation may or may not lead to a new market regime through a process of niche development and co-evolution. Hence, in terms of the four underlying perspectives identified by Durand (1992), the classification of Christensen, like Abernathy and Clark's, focus on the 'strategic output' for firms. The absence of a typology of market evolution led us to combine elements of the typologies of Christensen (1997) and Abernathy and Clark (1985) to elaborate the transition pathways typology of Geels and Schot (2007) into what we call a Regime Evolution Framework (REF). Our typology has a slightly different purpose as the typology in Geels and Schot (2007): rather than identification of transition pathways, it maps out the market evolution in general, with transition being one of the possible types. We increase the symmetry of their typology by applying two axes with four quadrants.

A final innovation framework proposed in the literature is the 'Industry Life Cycle'. By combining both product and process innovation in a single framework (Abernathy and Utterback (1978) and Utterback (1994) describe a typical technology development within an industry. These scholars found that the pattern of evolution displayed by the early US automobile industry (1900–1950) had similar characteristic of other industries, such as typewriters, bicycles, sewing machines, televisions and semiconductors. According to the authors, industries go through four phases: An early radical product innovation leads to many new entrants and to several competing designs (Phase 1: era of ferment). Process innovations and scaling up of production then lead to the emergence of a dominant design, the erosion of margins and a process of mergers and bankruptcies, ending with oligopolistic structure of a few firms (Phase 2: dominant technology). Incremental innovation then tends to prevail in both product and process (Phase 3: incremental innovation). A new wave of innovation can shift the industry back by to Phase 1 and start a new cycle.

The framework is certainly powerful because explains a range of empirical cases. We argue, however, it is no general typology and only applies under two conditions: (1) if the new innovation is disruptive for the industry (although the distinction of sustaining and disruptive innovation is not made in the concept), and; (2) if the disruptive innovation is successful, in the sense of overthrowing an established regime. The typology we develop in this paper is more general because besides including the emergence of sustaining innovation, it also includes unsuccessful cases of disruptive niches and the emergence of hybridization. In this respect, we see the Industry Life Cycle as one specific scenario happening within the REF, described next.

3. The Regime Evolution Framework (REF)

As various sociologists of technology and neo-Schumpeterian innovation researchers have emphasised, industry evolution is broader than organizational change. They have coined the terms *technological paradigms and trajectories* (Dosi, 1982) and later sociotechnical regime and sociotechnical landscape (Kemp, 1994; Rip and Kemp, 1998) to theorise innovation, with special attention to the embeddedness of technology in actor constellations, local contexts and historical settings (Weber, 2007, p. 113). The focal concern is not just with new products and firms but also with the structures, agents, and processes that reproduce a socio-technical practice and those that unsettle it. Smith and Stirling (2010, p.3) state that "some socio-technical systems are entrenched more deeply than others, in the sense that they enjoy greater institutional and infrastructure support, larger economic significance, better integration with other social practices, and broader political legitimacy". The alignment of existing technologies, regulations, user patterns, infrastructures and cultural discourses result in sociotechnical regimes that become the basis for decision-making (Geels, 2004). Alternative regimes can be contemplated but not easily realised because they have to go through processes of realignment and must compete against well-developed alternatives (Kemp, 1994). These regimes play an important role in the explanation for how the market evolves and why disruptive or sustaining innovation takes place.

Within this literature, an important theme is that of path-dependence, the phenomenon that choices of the past make certain choices in the future more likely and others less likely. A classic example is the QWERTY keyboard that most of our computers have, originating from the time of the mechanical typewriter when technical reasons led to this lay-out, but which remained when keyboards became electronic, even though other layouts would enable higher typing speed. Path-dependence in industries has been studied in formal models (for example in Arthur, 1989) to shown that increasing returns to adoption (positive feedback) lead to the lock-in of incumbent technologies, preventing the take up of potentially superior alternatives. In a later publication, Arthur (1994) identified four major classes of increasing returns: economies of scale, learning effects, adaptive expectations and network economies.

Path dependence at firm-level has also been highlighted by focusing on the knowledge and sunk costs. An example is Coombs and Hull (1998) who identify three potential domains for path-dependency within the firm. The first source is the knowledge embodied in the hardware or artifacts (i.e. the machinery and equipment of the enterprise), the second is the firm's knowledge base, which is connected to its technology and customers, and the third the collection of routines with which the enterprise conducts its regular business. Path-dependence may emerge in each of the three domains, as "the knowledge base structures the routines, which in turn deploy knowledge to create the technology, which in turn underpins the knowledge" (Coombs and Hull, 1998, p.243).

The sources of path dependence lie within and outside firms. In this respect, while Christensen focuses on internal factors, we are especially interested in those located outside, which refer to user practices and lifestyles, as well as new or underdeveloped technologies that would address user needs. In the case of mass-produced complex products, such as automobiles and televisions, technological advances follow a trajectory, a process of refinement of the dominant design (Utterback, 1994). The dominant design is usually based on the technological architecture of products around which a socio-technical regime has developed; a social context that is attuned to the technology (and vice versa) in terms of user practices (reflecting their preferences and endorsed social connotations), producer capabilities, business models and production technologies, regulations, and supporting institutions. Within this context, niche innovations based on alternative designs may be introduced or co-exist with the dominant one in the market or sector (Windrum and Birchenhall, 1998). Innovation of these niches accumulates to alternative (non-regime) trajectories. The various trajectories of regime and niches have their suppliers and users, researchers, product strategies and development agendas, organizations and level of momentum. Momentum refers to the level of 'dynamic inertia' (Hughes, 1987) that the trajectory has built up, and typically momentum is highest in the regime, but it may build up in disruptive niches, shifting the market in that direction.[2]

Fig. 2 presents the framework/typology of innovation modes of market evolution of technologies – the Regime Evolution Framework (REF), as we call it. The vertical dimension refers to the *nature* of innovation in the market. Niches may develop with strong links to the regime network (i.e. sustaining the regime), or provide an alternative socio-technical ensemble with weak or no links to the regime network (i.e. disrupting the regime). The horizontal axis of represents the levels of market share of the niches: the share of users shifting to a new or improved product, suppliers developing new competences and changes in the institutional environment. The market share may be small or large.[3]

Quadrant A (bottom left) represents incremental change within the established regime, with no notable innovations emerging in niches, called *Regime Reproduction*. Existing products remain dominant, serving the same user basis. What we have is a stable regime. An example of this is the car engine market between 1970 and 1995, when virtually all models were gasoline or diesel and all shared a similar internal combustion principle.

Quadrant B (top left) portrays the situation of disruptive innovations developing into new market niches. We call this *Regime amidst Diversification*. Even though the level of change is low, alternative producer capabilities and user practices gain a foothold in the market. The established regime now co-exists with one or more niches around disruptive products and practices. As we explore in detail later in this article, when the potentially disruptive niche of electric mobility for automobile powertrain technology emerged, for instance, it co-existed and co-developed next to the dominant design in the market. Another example comes from the energy sector, where wind and solar emerged as electricity generators after 1995 next to the traditional fossil-fuel sources (coal, gas etc.) and nuclear energy, championed by actors that were new to energy sector, indicating the diversification of the sector that these technologies triggered.

Quadrant C (bottom, right) is characterized by a high level of sustaining innovation within the regime. In this case, new product and process technologies emerge within the regime, but incumbents retain a strong market position. The social context of the market, user practices, market structure and producer capabilities and business models, sustains but gradually reorganizes. In other words, the established technology is gradually substituted with a new one, causing a *Reorganization* or redirection of the regime trajectory. An example from the consumer electronics sector is the shift from the first generation mobile phones to smart-phones (2000–current) with most incumbents adding smartphones to their model range, but in an altered competitive landscape (e.g. Nokia losing ground). As the smartphones were gradually used for computing purposes via dedicated applications, the regime was gradually 'reorganized' around the new sustaining (and hybrid) function of the phones. In this specific case, even though the innovation was 'sustaining' existing products, some companies faced major difficulties to develop competences and incorporate new functions into existing products.

Finally, Quadrant D in the top right corner of the figure represents a phase of high level of market penetration of disruptive innovation. Here, a *Transition* (Shift) towards a new market regime occurs. Many of the incumbent companies lose out against newcomers with new competences and product offerings, which go hand in hand with external changes. The new regime takes shape around new technologies, co-developing with alternative business models, production and user practices, often co-evolving with other markets and societal trends. An example is the transition from horse-drawn carriages to automobiles in America from 1875 to 1915. Rather than well-established carriage builders, new entrants constructed early automobiles by adding petrol engines, steam engines and electric motors to existing coaches and tricycles. The result was a *Regime Transition* in individual mobility; from horse-powered mobility to automobility. The transition also involved changes in infrastructure of roads, mainly involving new kinds of asphalt and concrete surfaces, as well as refueling stations (Geels, 2005).

Although we have portrayed the framework as four separate quadrants, the axes can also be seen as a continuum. For the horizontal axis this is obvious, depicting a market share from small to large, but the vertical axis too depicts the links of a niche innovation from very strong links to very weak links with the regime network. This way, the framework can accommodate cases in which disruptive or sustaining niches are difficult to characterize or are in an intermediate stage of evolution. In other words, the framework allows the mapping of the market interactions between sustaining and disruptive technologies overtime. In the next sections we show how the Regime Evolution Framework (REF) helps to do just that: classify innovation-based historical developments according to market evolution, as well as to theorize about possible paths for emerging technologies, as we do for the case of electric propulsion for cars.

4. Structuring historical developments with the REF

In this section we revisit the developments of two cases of technological and market evolution that are notably well-consolidated: the market evolution of steam trains and ships, two areas in which there is, with hindsight, little doubt about the winner technology.

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[2] Hughes emphasized how the supportive cultural context of a specific electricity supply system (the 'polyphase system') contributed to the system's momentum in the 1890s. At first, manufacturers reinforced the system's momentum by investing in resources, labor and factories to produce the equipment necessary for its functioning. Later, educational institutions contributed to the system's development by teaching students the skills needed to operate it. These practices were further spread and consolidated by professional journals. After this, research institutes were established to solve the system's 'critical problems'. All these factors contributed to the system's momentum (Hommels, 2005).

[3] It's important to clearly define the boundary of the market and niche considered. In case of low-end disruptive innovation the niche falls within the boundaries of the market, for instance Wal-Mart's cheap retailing as niche within the retailing market. On the other hand, new market innovation niches are an addition to the market they disrupt (so the total market size increases). For instance, the personal computer market was a new niche adding to the typewriter market.

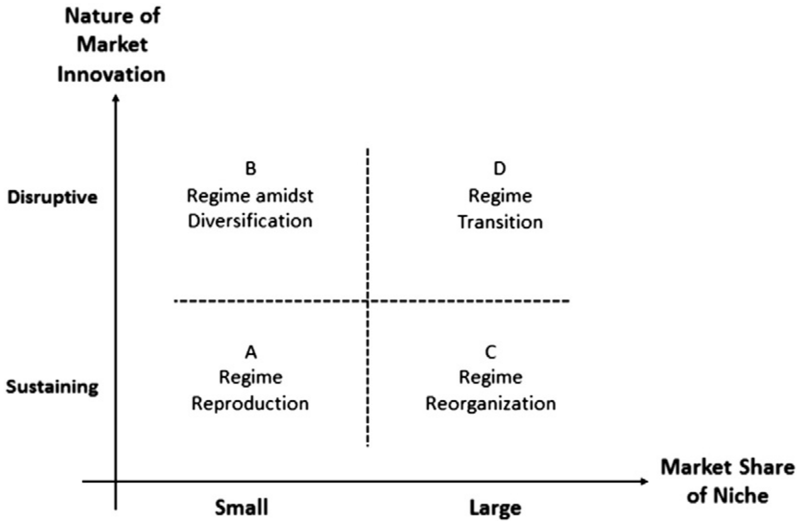

Fig. 2. The Regime Evolution Framework (REF).

4.1. The evolution of the British land transport market (1800–1860)

The co-development of different ways of inland transportation (i.e. transport other than walking) between 1800 and 1860 shows a dynamic that can be portrayed more clearly with help of the REF scheme. Fig. 3 depicts the innovation pathway of the market. The arrows connect four phases of high innovation *momentum*: groups of years with significant market share growth of a trajectory. The market share growth in such a period is schematically suggested in the Figure by the size of the rings. In the case of the land transport market, we measure the market share of a niche as passenger-km within the total passenger-km for land transportation (other than walking). Appendix 1 presents the underlying data and trend of the total market, including the concurrent developments in three socio-technical trajectories. Fig. 3 identifies four consecutive phases, with the arrows depicting their chronology. Initially, around 1800, transport in the UK was mostly dependent on the power of animals and the wind: the horse-drawn coaches or carriages over land, and the slower but cheaper horse-drawn barges and sailing boats over river and canals (Ransom, 1984). These two forms of transportation dominated and constituted the transport regime as two sub-regimes until the early nineteenth century. As Fig. 3 shows, since many roads were improved and fast reliable coach services introduced, resulting in better quality of the existing system, until 1825 most innovation had a sustaining nature - reproducing and reorganizing. Between 1800–1825 turnpike trusts, bodies set up by the British parliament with powers to collect road tolls for maintaining the principal roads, grew from 700 to 1000, maintaining a total of 29.000 km of road.[4] Moreover, iron-railed tram roads began to supersede old-established wooden wagon ways; and a nationwide network of canals was constructed, with boats being pulled by horses. However, after 1825 the growth of turnpike trusts fell back and by 1835 it was zero.

The foundations of a second phase (*Regime amidst Diversification*, Quadrant B) were laid around 1805 (although not gaining momentum until about 1825) with a potentially disruptive technology, steam engines, being applied to barges and other boats. At that time, the British engineer called Symington demonstrated for the first time the ability of steam to propel a boat that could do useful work (although there were earlier experimental vehicles). Although Symington himself benefitted little from his achievement, many others learned from his example, and soon achieved similar results. As one witness at the time remarked: "One of the most novel and useful applications of steam-engines has been to propel navigable vessels. It enables us to traverse the waters with nearly as much certainty as mail coaches travel land" (Dodd, 1818). The first commercial voyage followed soon, in 1812 by Henry Bell, who began to operate his little steamboat, the *Comet* on the River Clyde in Schotland. Steamboats started to replace many sail and rowed ferries throughout Britain, and within ten years of *Comet's* start there were nearly fifty steamers on the Clyde alone, and services had started on many British estuaries. Many time-conscious travellers, accustomed to travel by horse-drawn coaches, now started to use steamboats, especially on longer distances, because they were faster and convenient, at competitive prices. The steamboat benefitted from the canal constructions that were initially intended to support horse-drawn barges. By 1835, the Diamond Steam Packet Company, one of several popular companies, reported that it had carried over 250,000 passengers in the year (Dix, 1985). After 1825 some coaches were taken off, although the coach routes on and off the ports increased. Therefore, this second phase in which steam boats gained momentum, started broadly after 1825, characterizing the *diversification* of the market for land transport (Quadrant B in Fig. 2).

The third phase (still under *Regime amidst Diversification*) started around 1830, when the first British steam train lines

[4] Although trusts owned at maximum 20% of the total road network, we can be confident to assume that these were the parts where most passenger-km was driven, because they sought the most profitable trajectories.

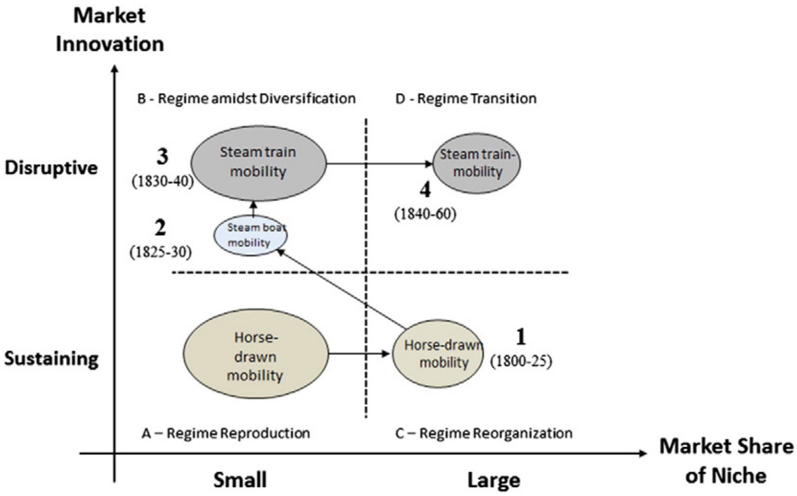

Fig. 3. The British land-based transportation market (1800–1860).

were gaining momentum. The first line between Stockton and Darlington had opened in 1825, with some fifty thousand people assembled to see the opening. The *Rocket* steam locomotive, demonstrated in 1829, was three times as fast as any horse. Such speed was attractive for travellers, since it eased the way for longer travels, and through a business model with three different classes of travellers, with corresponding prices and comfort levels, prices were competitive for both those who were used to travel by horse-drawn coaches and those accustomed to barges. Moreover, the third class tickets opened up a latent market for people who liked travelling but hardly travelled before (Van der Woud, 1987). When the line between Liverpool and Manchester opened in 1830, fourteen of the twenty-six local road coaches withdrew and by 1832 there was only one left. During the 1830s and 1840s private investments extended the network of steam railways at a high pace, overtaking canal and coaching developments. As a result, steam trains, introduced by 1830, became responsible for more than 50% of the total passenger-km at land in the course of the 1840s. In other words, a *transition* in land-based transportation had taken place towards a market dominated by steam train mobility (Phase 4, Quadrant D in Fig. 3). After 1840 the rail network was further extended (between 1842 and 1850 from 2570 to 9790 km [Ransom, 1995]), the speed of the locomotive increased (from 30 km/h by 1840 to 90 km/h by1890) and the steam engine efficiency was improved, which meant that less coal was needed for locomotive power.

In sum, the transition in land-based transportation occurred very fast: within a period of 15 years, the regime of horse-drawn coaches and barges was replaced by a regime of steam trains. This is much faster than the transition to steam ships, as we find in the next section. The proposed regime-based typology helps to clearly distinguish regime disruptive from regime sustaining developments in the analysis, as well as to indicate the level of change. The niche of steam trains and steamboats were both disruptive in character for two main reasons. For consumers, both steam boats and trains did not offer incremental improvements of customary attributes of travelling, but rather a giant leap in the speed of travelling (trains soon being five times as fast as carriages and barges), which made speed widely appreciated and it soon became a prominent attribute for the mass (Van der Woud, 1987), and moreover they offered the benefit of steady navigation (independence of wind or animals and for trains also from winter frost). For transport operators, steamboats and trains meant a very different business model than carriages and vessels, not in the least because of their higher purchase price. The operation and maintenance of the vehicles also required different competences; instead of feeding a great number of horses, the main competence was on the logistics of coal for fuel. Therefore, it should not be surprising that most of the operators of trains and steamboats were new market entrants, while operators of carriages and sailing boats faced difficult times. Overall, both steamboats and trains had the potential to change the ‘order of things’ in inland transportation, and whereas steamboats were on their way to do so, steam trains overtook them.

4.2. The evolution of the British sea transport market (1800–1900)

The introduction of steam propulsion in river and canal boats also affected the sea-based sailing ship market, although in a very distinct way. Fig. 4 summarizes the progression of innovation momentum in the British sea shipping market in four consecutive phases, illustrating that the replacement of sail by steam was a far more gradual process than the replacement of horse by steam on land. In the case of steam trains the time from introduction of the disruptive innovation (1825) to the start of transition (1840) was 15 years; in the case of steam ships it was 47 years (from 1833 to 1880).

We measure the market share of a niche here in terms of registered tonnage within the total British sea shipping market (which includes freight, passenger and naval ships) and again we group years with significant market share growth. Unlike land transport, which had been developing steadily over the first quarter of the 19th century, sailing ships had been evolving

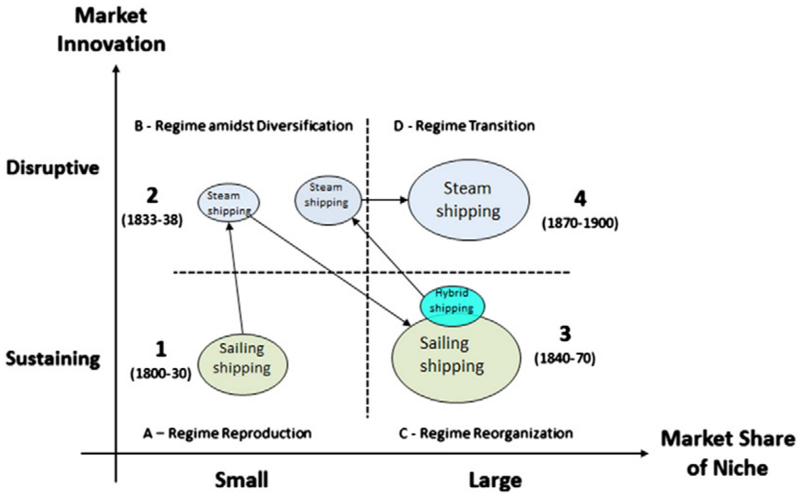

Fig. 4. Phases of innovation in the British sea shipping market.

more gradually for the three preceding centuries and the three-masted ship had remained unaltered in principle, although it had six times as many sails as in Columbus' days (Clowes, 1930). Until 1830 such incremental innovation continued through the increasing size of the ships (without substantial changes in the rigging of the ships), the rise of shipping entrepreneurs (professional ship owners who would lease their ships to traders), and the introduction of scheduled packet services. This period is characteristically one of *Regime Reproduction*, as depicted in Quadrant A in Fig. 4.

The second phase (*Regime Diversification*, Quadrant B) initiated with the introduction of the iron steam ship by 1833–38, a disruptive technology that had been invented much earlier but remained marginal in terms of market penetration. The first successful steam voyage at sea was already in 1818, between Glasgow and Belfast, and subsequently a commercial service was established there. In 1819 the first cross-Atlantic voyage followed, between the USA and Britain, by a sailing vessel with auxiliary steam propulsion. Now, by 1833, the first successful west-to-east crossing of the Atlantic under steam all the way was made by the Canadian PS *Royal William* and a regular steamship service across the Atlantic was established in 1838. However, this phase ended soon, since the companies set up to operate transatlantic steamer services did not have long lives, mainly due to problems in their vessels (Ransom, 1984).

After 1840 a remarkable third phase with a sustaining nature (*Regime Reorganization*, Quadrant C) started, in which the attractiveness of the established technology reestablished itself. The owners and builders of sailing ships realized that the time had come for them to improve the speed of their vessels if sail was to remain profitable. They increased the length-width proportion of the hull (increasing the number of masts) and a consequent increase in speed enabled the sailing ship, or 'clipper' as it was called, to compete economically with the steamer in East India, China and other long-distance trades, especially for tea and opium. Also, sailing ships continued to become larger through the introduction of iron hulls and steal masts (Geels, 2005). Through these two developments sailing ships became significantly faster and larger over the whole period between 1840 and 1870.

Another key phenomenon in this period was the development of hybrid ships. Until the 1880s, most steam ships were, in fact, steam propulsion with sails. There were distinct reasons why 'steam only' was not the most attractive option at the time. For merchants, the speed of steam propulsion was attractive, but since engines and boilers of early steamship were so inefficient, their coal consumption was very high. For a long voyage, much time was lost in coaling and much space had to be devoted to coal bunkers, with a resulting reduction in cargo-carrying capacity of the vessels. This removed much of the advantage of steam propulsion. For naval officers, a second group of clients at that time, the paddle-wheels of the first generation of steamship were too vulnerable. For them, steamers became only attractive when the screw was successfully refined in the 1850s (after being introduced in 1843). Notwithstanding, the combination of sail and steam was also preferred in order to limit the space needed for coal and save coal for the time of a combat. For ocean passenger vessels, the third group of ship clients, the steam ship was most attractive because of its speed and independence of wind, and for this reason this was the group of early adopters of the 'steam only' option.

Only gradually the disruptive steam technology gained an edge over sailing for a broader group of users, substantially increasing its market share only after 1870 and, in the REF, moving into the fourth phase of *Regime Transition* (Quadrant D) by 1880. In the 1860s fast sailing clippers were still competitive with steam for long distance carriage of cargo. The total tonnage of British steamships did not equal that of sailing ships until the 1880s; by then the economies resulting from the introduction of compound marine steam engines and later on triple expansion engines were giving steamships the edge. In particular, the opening of the Suez Canal in 1869 benefitted steam voyages to the east, since sailing ships could not be used (Fletcher, 1958). For marine vessels, the year 1862 became a milestone for the steam-powered CSS *Virginia* destroyed the sailing ships USS *Cumberland* and USS *Congress*, shifting the preferences of British (and other) naval officers

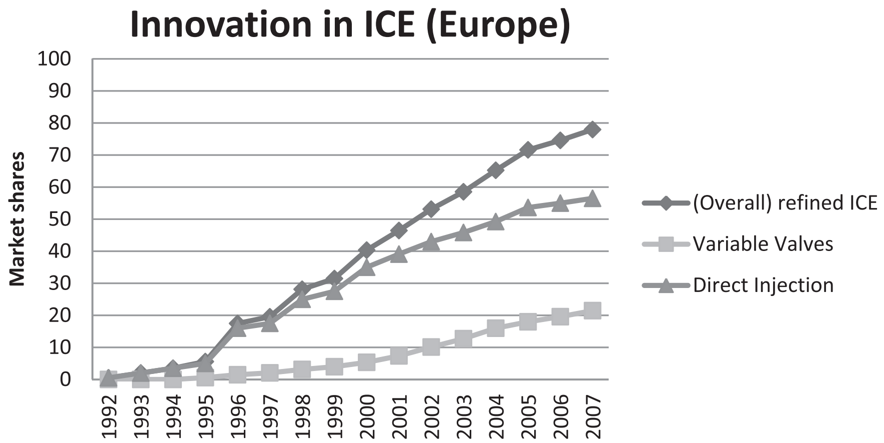

Fig. 5. Incremental innovation of the ICE regime through diffusion of Direct Injection and Variable Valves in vehicles sold in a year. Both diesel and gasoline account for about 50% of the market in Europe. (Source: own calculations, based on data provided by Bosch and Delphi).

towards steam. Demand for steam-based passenger vessels benefitted from the growing market of transatlantic passenger transport after 1850.

In sum, although steam propulsion for ocean voyages seemed to be perfect in terms of the independence of wind, the momentum around 'steam-only' initially stalled for 30 years, while the regime around sail ships reorganized. Only after 1880 steam ships became dominant in terms of use. Overall, the replacement of sail by steam at sea was a far more gradual process then the replacement of horse by steam on land, partly through hybrid designs.

5. Structuring emerging developments with the REF

The use of the REF to structure well-established historical innovations gives us ground to explore it for the analysis of emerging developments. Today, the discussion about the potential success of alternative powertrain technologies for cars can be found in both empirical and theoretical realms. Will battery electric vehicles (BEVs) come to dominate the regime of individual motorization, at the expense of vehicles powered by internal combustion engines (ICE)? Will the regime of individual motorization follow a similar pattern as the regimes for land transport or sea shipping (described in the preceding section)? In this section we use the REF to analyze the regime in the existing car engine market (measured in terms of total number of passenger vehicles sold in a year) and answer these questions.

5.1. The evolution of the individual motorization regime

In the last two decades, the automotive sector in Europe has demonstrated increasing attention to alternative propulsion systems. Next to the established and dominant internal combustion engine (ICE) technology, automakers developed battery electric vehicles (BEVs, with market launches in the middle of the 1990s and after 2010), hybrid-electric vehicles (HEVs, launched in 1997 in Japan, 2000 in Europe) and fuel-cell vehicles (FCV, no series production yet). But despite such technological novelties, the technology embedded in ICEs also evolved over the last 25 years. (Dijk and Yarime, 2010; Dijk, 2011) explored the market diffusion trends of new ICE components and prices next to the evolution of consumer preferences and suppliers. They found significant innovations of ICE components, through the steady diffusion of direct injection systems and variable valve systems after 1995 (see Fig. 5) and slow diffusion of electric propulsion technologies between 1990 and 2010, with only a few percentages of market share for HEV, whereas EV and FCV remained negligible. As a result, three unfolding innovation trajectories were identified: (i) the established (ICE) regime trajectory and (ii) an electric mobility niche trajectory, which comprises both electric and fuel-cell vehicles, and (iii) hybrid-electrics as an intermediate solution.

Geels et al. (2012) elaborated on the findings of Dijk and Yarime (2010) and found that electric propulsion requires new capabilities at the supply side and positive appraisal from consumers. In parallel to the incremental innovations of ICEs in the 1990s, automotive suppliers developed capabilities in electric, hybrid-electric and fuel cell vehicles, offering specifically designed electric vehicles. While electric vehicles improved, consumers still favored ICE vehicles. The reason for this is straightforward: full battery electric vehicles (BEV) still have low range (kilometers per charge) and high battery costs, representing a major purchase barrier - even for committed green consumers (Higgins et al., 2012; Gardner and Ashworth, 2008; Line and Greene, 2010).[5]

[5] Supported by an analysis of actual sales in the Netherlands, although probably exemplar for other countries, Dijk (2011) recognizes three consumer segments for new cars: for the first group (in size about 35%) price is the most salient attribute. They are satisfied with the functionality of the cheapest engine. The second group (about 60%) is willing to pay more for a stronger engine. Adopters have different reasons for this: typically to drive more conveniently on the highway, or because they like sporty driving, for status, or to pull a caravan. Thirdly, he finds a small 'green car' segment, that is a group of consumers willing to pay more for a cleaner engine, comprising of only a few percent of the consumer base (of those who buy a *new* vehicle).

When HEVs became a market reality with the launch of Toyota *Prius* in 1997, consumers compared HEVs with ICEs, notably their fuel economy (higher for non-highway drives), prices (higher), engine capacity (sufficient, not spectacular), range (similar), and engine noise (more silent); with most consumers still preferring ICE cars. Before 2004, the modest sales of BEVs and HEVs (with a market share of less than 1%) hold up both the development and further diffusion of electric vehicle technology. Due to the small market, firms were unable to take much advantage of economies of scale. Most suppliers were reluctant to further invest in pure or hybrid electric propulsion. This was in sharp contrast with the new ICE components, which benefited much from economies of scale (see Fig. 5).

After 2004, with the second generation of Prius, Toyota was able to reach dispersed green consumers worldwide, and when various countries introduced financial support schemes for hybrids, some price-minded customers were attracted to hybrids as well. This modest but significant success, despite still poor economies of scale for hybrids at the time, can be explained by the social and political context of the sector. Concerns about the climate and geo-political scarcity problems associated with fossil fuel use induced many to propose hybrid vehicles as 'the right vehicle for society'. After 2005, HEVs were increasingly seen as green and trendy (Heffner et al., 2007). Apart from influencing consumers, this social praise for hybrids also drove political support for tax discounts on HEVs in many countries. After 2005, actual purchases of HEVs went up considerably; much more than BEVs in the 1990s. This trend stimulated car firms to give more priority to building the necessary capabilities for the development of electric propulsion systems (pure or hybrid).

The understanding the market evolution in vehicle technology in the last 25 years, as well as the exploration of potential futures can be significantly enhanced by the use of the Regime Evolution Framework (REF). Fig. 6 summarizes this evolution in five phases (with the market measured in terms of total number of passenger vehicles sold in a year).

In the first phase, until about 1995 (*Regime Reproduction*, Quadrant A), we found incremental (sustaining) innovation of the dominant regime technology, internal combustion engines, most importantly through advancements in the number and lay-out of the valves and wider application of turbocharging.[6] The second phase (*Regime amidst Diversification*, Quadrant B) is a somewhat odd phase of electric vehicles being launched in the car market by most large manufacturers, triggered by regulation in a few American states, not consumer demand. This meant that the market diversified, since a disruptive technology (BEVs) gained some momentum, even though sales were poor. After 1997, the growth of electric models stopped and most of the available models were even withdrawn from the market, while only a few firms incorporated electric propulsion in hybrid ICE-electric vehicles. Most firms focused on the conventional ICE engine, and diesel in particular went through a period of major improvements with direct injection systems becoming widely applied and, later on, particle filters added to ICEs. This characterized phase three in the REF – a 'return' to a *Regime Reproduction* scenario (Quadrant A). Even though hybrid vehicles had the potential to trigger more profound changes in the regime, their market penetration was very limited – the reason for the innovations to be dotted in the Figure.

The fourth phase (*Regime Reorganization*, Quadrant C), broadly after 2007, is a period in which the growth of hybrid models and their market share stalled and the regime around the ICE technology develops an increasing number of cleaner models, integrating more electronics into the established technology. Apart from Toyota and Honda (and to a lesser extent Ford), other carmakers postponed their plans to launch HEVs. Instead, firms focused on launching so-called *cleantech* versions of internal combustion engines, which includes electronic start-stop systems, regenerative braking and special transmission software, with Volkswagen's *Bluemotion* series being one of the early movers in 2006. Both the eco-friendly versions of ICEs, which include an extended amount of electronic components (and are therefore called micro-hybrids), and full hybrid-electric vehicles, can be considered examples of *hybridization* of the ICE technology – the latter being a stronger form of it than the first.

Throughout this overview of the past two decades of developments in individual motorization we witnessed the stability of the regime around the internal combustion technology. After the introduction of disruptive innovation in 1996, incumbent manufacturers have responded primarily by further investments in innovations sustaining ICE-based mobility. The re-introduction of battery-electric vehicles after 2010 in Europe, such as the Nissan Leaf, Peugeot iOn and Smart ED, and the announcements of other firms, suggests a new phase of momentum around full electric drives starting (phase 5, in Quadrant B). Since it is too early to foresee the developments after 2012, we also dotted the innovations of Phase 5 in Fig. 6.

The REF may help to sketch scenarios by highlighting the key distinction between regime sustaining and regime disrupting innovation. Scenarios can be imagined between the two extremes of the scheme: either the re-introduction of BEVs attracts momentum like steam trains and disrupts the market profoundly, or the reintroduction triggers reorganization of the ICE regime, leading to a reinforced regime that is even better occupied to resist disruptive influences.

The socio-technical space sketched by the REF may support scenario development exercises in various stages. For instance, it can be used to build scenarios linking innovations with their supposed market share. Also, the REF may help to assess the robustness of a set of scenarios developed elsewhere. Each scenario can be depicted in the REF as journey of a possible future, in the same way as we have sketched the journeys of historic markets. This explicates the level of disruptive innovation that is assumed in a specific scenario and triggers the discussion of how robust and coherent assumptions are. For example, national policy plans and roadmaps easily assume millions of EVs on the road by 2020, without discussing their assumptions. The REF would help to expose the assumptions of, for instance, a growing disruptive niche amidst of a well-developed and refining regime of established ICE cars.

[6] We start our case study after all European ICE vehicles had their carburetors being replaced by electronic injection systems, by 1992.

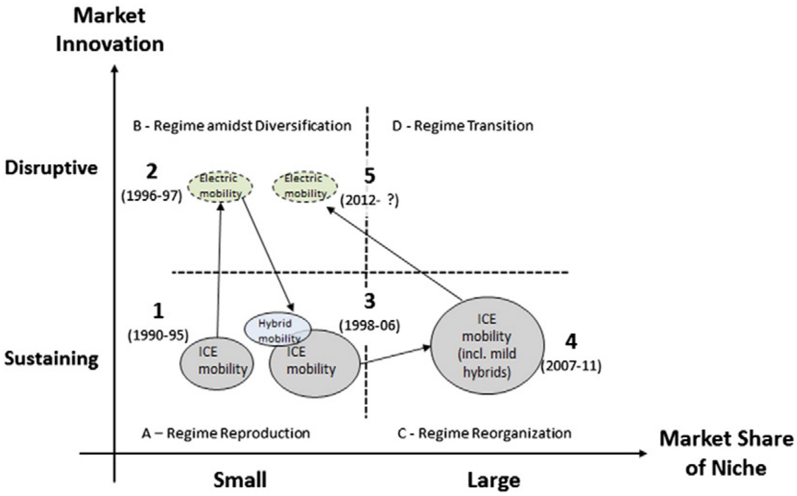

Fig. 6. Phases of innovation in the European automobile market.

6. Conclusion

This paper contributed to the theorization of innovation by developing a typological framework and applying it to both well-established cases and emerging cases of technological evolution. Indeed, the contribution of the Regime Evolution Framework (REF), as we call it, can be showed via practice. Instead of using the REF, in this final section we examine the mileage of the framework proposed by Abernathy and Clark (1985) and Christensen (1997) to analyze the evolution of the British Land Transport Market (1800–1860).

Based on the prerogatives of the work developed so far by Christensen, we can infer he would possibly offer a firm level analysis, as well as a discussion about the dilemma successful coach operators would face, confronted with the introduction of potentially disruptive steamboats or trains. The analysis would include the threat and opportunities for the firm to increase competitiveness by strategically anticipating the introduction of steam mobility. Such analysis would give an insight into the alternative strategic options that a (profitable) coach operation in 1825 or 1830 had. The business case could be made with a firm that successfully re-focused its coach business from intercity trips towards on-and-off transport to major railway stations; one that started a steamboat service, and/or one that failed to re-organize and collapsed.

Similarly to Christensen, Abernathy and Clark can be expected to apply a firm level perspective to evaluate a range of innovations. For instance, they would possibly discuss various innovations that a coach operator introduced between 1820 or 1840 and its implications for the success or failure of the business. As Abernathy & Clark did for the automotive innovations of Chrysler between 1924 and 1949 (ibid: 19) they would have used their framework to locate a specific product-focused innovation in one of the four quadrants. For the land mobility case, this would include how coach operators improved suspension of the coach or adapted their route-network, for instance. The first innovation would be plotted as regular, a new route-network focused on in-and-off transport to harbors and rail stations designated as niche creation, and the introduction of steam boat services as architectural innovation. In sum their framework would provide a chronology of the introduction of innovations by the coach operator; certainly not of their market shares. Since many innovations fail, such a graph would not depict market evolution but the evolution of the strategic focus of the firm. Even though the analysis of Christiansen and Abernathy & Clark would also represent a valuable contribution, they would not expose the market-oriented elements, as we did in our analysis.

The REF framework characterizes the periods or phases in the evolution of the market (as regime reproduction, reorganization, diversification or transition). By mapping out the market evolution in a socio-technical space, it helps to clearly distinguish innovations that sustain the regime from innovations that (jointly) disrupt a product regime. Therefore, more than diffusion curves or market share numbers, the REF is instrumental to highlight a socio-technical pathway of innovation in the market in the course of a few decades, with special attention for sustaining and disrupting innovation. Even though the perspectives of Christensen and Abernathy & Clark are instrumental to understanding the firm level business perspective, the REF provides a framework to depict the evolution of the market in which the latter businesses are involved. The three perspectives complement each other in providing explanations to the market evolution pattern. Christensen, Abernathy and Clark are a source of explanation for the firms' behavior (and their success and failure). Supplemented with studies about consumer practices, government regulation or other institutional developments, they provide sound explanation for how the market evolves over the course of a few decades.

A disadvantage of this approach may be that it requires a good deal of quantitative data on market shares of the various innovations in the market, something that may be difficult to obtain.[7] Also, when depicting the trends of market shares in the

[7] For very early stage or disruptive technologies, the market itself may even be difficult to define. Also, some incremental innovation in the regime may receive little attention with data on shares hardly available. Obviously, the more data available, the more precise the pattern of momentum (i.e. rate of change of market share) can be sketched.

REF, it is important to clearly define the boundaries of the market. Especially in case of disruptive 'new market' innovation, when a new market is added to an existing one (that is being disrupted). For instance, when the new PC market disrupted the typewriter market, the total market would be indicated as total sales of typewriters and PCs.

The study of both established cases (ships and trains) and emerging ones (automobiles) suggest that the notions of sustaining and disrupting are not technology-inherent qualities that can be attributed *a priori* but depend on how the technology is applied to a product and manifests itself in its features. For instance, we have classified the introduction of steam propulsion in land-based transportation as a disruptive innovation. However, if steam propulsion would have been introduced in carriages (and some have experimented with this), it may have triggered regime-sustaining transformation instead of the transition to trains. Nevertheless, as soon as steam propulsion was applied to trams rolling on wagonways (later called trains on railways) it disrupted the regimes of horse-drawn carriages and vessels. In other words, as soon as we use a concrete product (as opposed to a technology) it becomes clear whether the product is regime sustaining or disruptive in character.

Nevertheless, as we have illustrated, sometimes elements of an emerging disruptive product are drawn into the established technology, forming more radical sustaining innovation. So what seemed disruptive innovation at a first glance, turned out to contribute to strengthen the regime. The cases of sailing ships in the 19th century and electric cars in the early 21st have illustrated this pattern of hybridization and, accordingly, we find the REF scheme useful to compare markets and find similarities and differences in technological evolution. In both cases, the pattern results primarily from defensive strategies of incumbent firms, which find hybrid solutions a less risky strategy.

In this respect, the REF may facilitate scenario analysis in inconclusive developments, building on the rich insights of historic market patterns, including hybridization. For the future of powertrain technologies for cars, for instance, scenarios may include: (i) a further expansion of hybridization technologies, making the current regime only stronger, remaining in place for decades to come. However, the analysis of the now consolidated British Sea transport market suggests that hybridization can only be an intermediary phase till the disruptive technology matures. In the case of automobiles, this would mean hybrids to be temporary phase before a regime transition to full-electrics.

Our paper only introduces the REF as a way of structuring market evolution, and we suggest future studies are necessary to elaborate on how markets evolve in the cases we addressed, as well as in others. The value of the REF should be further explored by analyzing other sectors, both historic and ongoing, such as the ones in the mobile computing and communication (laptops, tablets, phones, video cameras, etc.) so to determine whether there are similar patterns of regime evolution as those studied in this article. Other stylized patterns may emerge out of such research, next to the pattern of hybridization that we highlighted. The result of this kind of research would be of great value for theory development in innovation.

Acknowledgements

We are grateful for the comments of the editor and three anonymous reviewers, which greatly helped to improve the paper. Marc Dijk acknowledges the Oxford Martin School for hosting a research fellowship, and participants of a seminar on this paper at the Transport Studies Unit, Oxford University in the third quarter of 2012.

Appendix 1. British land transport market (1800–1860).

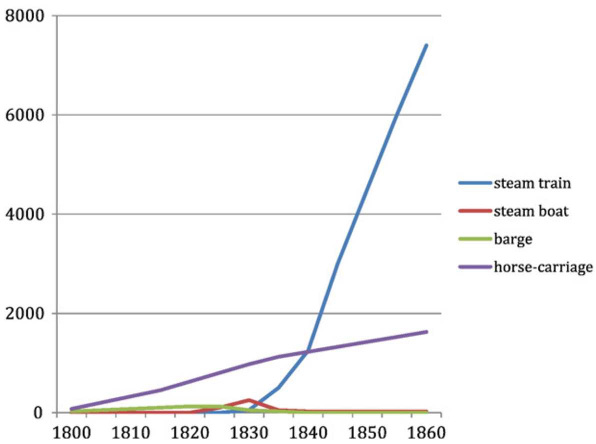

Fig. A1. Estimates of passenger kilometres per mode.[8]

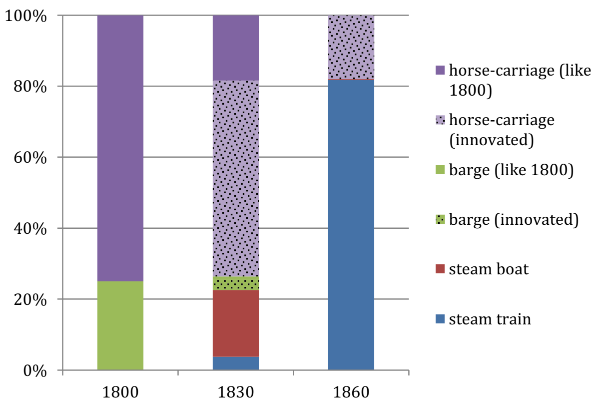

Fig. A2. Shares of the various modes in 1800, 1830 and 1860 in the total of the four modes in the respective year.

[8] These are estimates based on the scarce available data from this period (Bagwell, 1988: 31–42). Bagwell estimates that by 1835 there were 15 times as many coach passengers than 40 years earlier. By 1835 he estimates 10 million coach journeys, with another three quarters of other types of horse-drawn carriage journeys adding up to 17.5 million of horse-carriage mobility. By 1845 the number of rail journeys is about 30 million, by 1870 about 336 million. The y-axis shows passenger kilometers (as a relative unit with base year 1800 as 100).

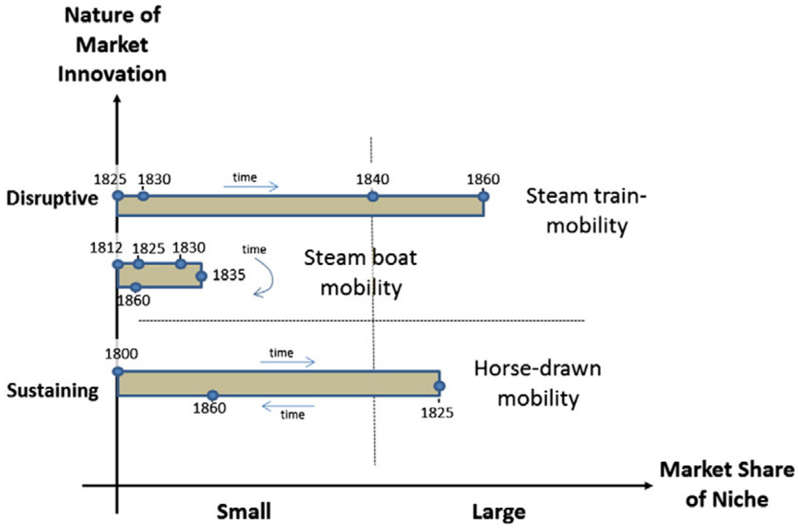

Fig. A3 Three socio-technical trajectories developing over time in a sustaining/disruptive perspective (each trajectory with one's own timeline).

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