DO PRE-EXISTING STANDARDS AND REGULATIONS HAMPER OR STIMULATE THE DEVELOPMENT AND DIFFUSION OF RADICALLY NEW HIGH-TECH PRODUCTS?

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Abstract

There is controversy among scientists whether standards and regulations hamper or stimulate innovation. We investigate the direct effect of standards and regulations on the development and diffusion of radically new high-tech products. The radicalness and degree of inter-relatedness of the technology in these products are found to moderate this direct effect. The focus is on pre-existing standards and regulations, i.e., the standards and regulations available in the industry prior to the development and diffusion of the products and therefore also not specific for these products. The effect on development and diffusion is assessed in terms of the time interval between the invention of a technological principle and the introduction of the first marketable product based on that principle (development phase), and the successive time interval that covers the period up to the start of industrial production and large-scale diffusion (adaptation phase). We analyse fifty heterogeneous cases of radically new high-tech products from the year 1850 onward. Our results indicate that pre-existing standards and regulations significantly shorten the adaptation phase; this effect is not found for the development phase. The effect on the adaptation phase is moderated by the radicalness and the interrelatedness of the technological system required for the product. That is, pre-existing standards and regulations shorten the adaptation phase in particular for products that are part of radically new (at the time of their introduction) and interrelated technological systems. As the adaptation phase is often a time- and capital-intensive phase for industry, this accelerating effect on the diffusion is highly relevant for innovation managers and policy makers.

Keywords: standards, regulations, high-tech, innovation, diffusion

1. Introduction

The question whether standards and regulations hamper or enable the development and diffusion of radically new high-tech products has created controversy among scientists. The policy and managerial importance of resolving this controversy goes undisputed. The nature of the relationship needs further clarification. With this paper we contribute towards this goal. We focus on *pre-existing* standards and regulations. Pre-existing standards and regulations refer to the prevailing set of standards, rules, laws and conventions available in an industry prior to the development of a product. These may have bearing on interoperability between complementary products and services, compliance to safety and quality requirements in an industry, and so on. Because these standards and regulation are available prior to the development of a product they are also not specific for that product. Pre-existing standards and regulations are part of the industry conditions in which a product has to evolve.

We focus on radically new high-tech products. The contraceptive pill and Nylon, for example, have in common that, at the time of their introduction, they were radically new in the market and state-of-the-art in their respective disciplines. Radically new in the market means that their functionality was new to the market or the price-performance ratio was much better than that of contemporary products. State-of-the-art in their respective disciplines means that the products were based on new technical principles (e.g. contraception using hormones) or were based on an existing principle but with a much better price/performance ratio. Following the typology proposed by (Garcia and Calantone, 2002) we therefore refer to them as radically new.

In some cases, such as SMS, pre-existing standards and regulations can facilitate the development and diffusion of radically new high-tech products. SMS is a short message text service sent via the D-channel of the ISDN network protocol, a channel that was originally meant for traffic control only. The availability of this standard and of regulation regarding the structure of the telecommunication network eased the development and diffusion process of the SMS-service (Brusoni and Corrocher, 2006; Lacohée, Wakeford and Pearson, 2003; Taylor and Vincent, 2005). However, in other cases pre-existing standards and regulations can hamper the development and diffusion of radically new high-tech products in an industry. Kay (2002) and Constant (1980), for example, illustrate this with respect to the jet-engine developments in both Germany and Britain at the start of the Second World War. In both countries the entire military air force system was organized around propeller-powered airplanes.

A key issue in the afore-mentioned scientific debate is that some scholars perceive standards and regulations as limiting variety and, more specifically, as restricting innovation (Temple, 2005) and product variety (Wölker, 1996), while others view them as allowing the build-up of critical mass and enabling economies of scale (e.g., Swann, 2000; Blind, 2004). A possible cause for these contradictory findings is the lack of specificity about the timing of standardization and regulation. Standards and regulations may already be in place at the time of the invention. However, they may also be developed and effectuated at a later stage (Egyedi and Sherif, 2010). Whereas the adverse effects of standardizing and regulating too early or too late are well-noted (Blind, 2004, p.40), no systematic enquiry has been made into the way pre-existing standards and regulations influence different phases in the process of development and diffusion of radically new high-tech products (West 2003; Temple, 2005).

From a scientific perspective it is highly relevant to resolve the controversy and clarify in what situations and manner pre-existing standards and regulations affect development and diffusion. Better insight into their effect may help design institutional and policy frameworks that can better catalyse development and diffusion processes. Such frameworks are needed to support more effective innovation policy at the governmental and company level.

In this article, we aim to clarify a few issues that cloud the debate. In particular, we explore the effect of pre-existing standards and regulations on the time required for different phases in the trajectory of development and diffusion of radically new high-tech products. We investigate this effect for a heterogeneous set of cases from different historical periods and industries.

The article is structured as follows. In the next section, we address theoretical considerations, such as the controversy about the impact of standards and regulations on innovation. In section three and four we present our methodology and research findings. In section five, these findings are then illustrated in two cases. We close with a conclusion and discussion section and a section on future research.

2. Theory

2.1 Debate on the effect of standardization and regulation on innovation and diffusion

Past studies are not unanimous about the effect of standardization and regulation on development and diffusion, as overviews of the literature show (Swann, 2000, 2010; Blind, 2004; SOU, 2007). Some emphasize the terse relationship between the two, and in particular the inherent variety reducing effect of standardization on creating novelty, which is a key characteristic of innovation. Standards can be seen as freezing or fixing technology development (Hanseth, Monteiro and Hatling, 1996; de Vries, Verhagen and Beerepoot, 2008). Blind's provides a list of authors that see standardization as constraining innovation (2004, Table 4.1, pp.22-26), and argue that standardization limits product diversity and consumer choice (e.g., Wölker, 1996). Where de facto standards are concerned, this may lead to market concentration and monopolies (Blind, 2004, p.22). Monopolies impede the transition from an old to a new technology (vendor lock-in) and reduce incentives to innovate. Where committee standardization is concerned, however, on closer scrutiny many of the negative effects mentioned by Blind (2004) are not the consequence of standardization per se but of wrong timing, an ill-advised choice of what is to be standardized, a 'politicized' standards process, or of the way standards are implemented in products or services. Thus, Senden and Wöckel (1997) speak of *inflexible* standardization that "cement[s] the state of technology" and "cut[s] down on other variations in the interest of standardization"; and Salop and Sheffman (1983) point to the possible occurrence of 'regulatory capture', whereby minimum quality standards (e.g., for safety) are defined in a way that highly raises the costs of innovation for rivals. In an attempt to weed out ill-targeted standardization and misuse of standards in their studies of the impact of committee standardization on innovation, some authors use the term 'effective standards' to indicate their focus (Swann, 2000, 2010; SOU, 2007).

Reviews of the field also highlight findings claiming that standardization enables technology innovation (Swann, 2000, 2010; Blind, 2004; SOU, 2007). As summarized by Swann (2010, p.9):

> *"standardization helps to build focus, cohesion and critical mass in the formative stages of a market (e.g., Krechmer 1996; Swann and Watts, 2002). Standardization of measurements allows innovative producers to demonstrate to the satisfaction of the customer that products are as innovative as they claim to be (e.g., Tassey, 1982; Swann, 1999). Standardization codifies and diffuses state of the art technology and best practice (e.g., Krechmer 2000, 2005; Blind and Grupp, 2000). Open standards are desirable to enable a competitive process of innovation-led growth (e.g., Krechmer, 1998; Swann, 1990)".*

The question why standardization enables development and diffusion, here confined to committee standardization, seem to hinge on two substantially different explanations. According to the first explanation, standards are seen as an infrastructure, a shared basis for technology development. According to this line of reasoning, standards are a means to reduce transaction costs, facilitate trade, build critical mass and allow economies of scale. The second explanation focuses on standards as embedding information that spurs development and diffusion. According to this line of reasoning, standards codify and share state of the art scientific and engineering knowledge which is put to use by innovators.

In this paper, we empirically explore the impact of pre-existing regulations and standards on development and diffusion. In this area, Swann (2000) and others (DTI, 2005; King, 2006;

Swann and Lambert, 2010) have done pioneering work. To address the question 'Do standards enable or constrain innovation', Swann analyses the response of companies to two questions in the Community Innovation Survey (CIS3; period 1998-2000; DTI, 2005, p.80).

Question 8.1 asks the respondent to comment on a range of factors that may inhibit the enterprise's ability to innovate[1], including the 'Impact of regulations or standards'. The respondent is asked to grade the importance of these constraints.
Question 12.1 asks respondents to rank the different sources of knowledge or information used in innovation activities. The sources include 'Technical standards, Health and safety standards and regulations, and Environmental standards and regulations'.

Swann demonstrates that the two issues are positively correlated. Respondents saying that standards are a source of information for innovation activities also indicate that these standards and regulations constrain their innovation activities, and vice versa (DTI, 2005; Swann, 2010, p. 10). Swann and Lambert (2010) therefore rephrase the research question as 'Why do standards enable *and* constrain innovation?'

King (2006) specifies why this may be the case. Using additional CIS data on the 'effects of a firm's innovation activity' (King, 2006, p. 72-73), he concludes:

> *"It is clear that the pattern for the constraint imposed by regulations paralleled that (…) for the use of standards as a source of information. This suggests that those who make use of standards to help them achieve a particular goal feel to some extent constrained by them. Moreover, Swann argued that the 'informing' and 'constraining' roles of standards were complementary, and these results support his claim. Standards documents provide guidance and stipulations concerning best practice for ensuring rigorous quality control, and specifications to enable compatibility and minimum levels of performance. Hence, standards inevitably constrain a firm's activities if they wish to receive the benefits that standardization brings. Finally, regulations may force firms to innovate and adapt their practices in order to comply with regulation, and in such circumstances firms are necessarily constrained by regulation. In essence, taking account of standards and regulations is part of the routine that successful firms follow." (King, 2006, p. 76)*

In sum, according to this set of studies, the question whether standards and regulations enable or constrain innovation contains a false antithesis (Swann and Lambert, 2010, p. 371). Standards and regulations can at the same time be a constraining as well as an enabling force for innovation.

2.2 Process of development and diffusion

The timescale for the development and diffusion of radically new high-tech products can vary widely. Some of these products show a life cycle that unfolds within a few years while for other products this may take more than a century. Different types of life cycles have been distinguished in the literature. Sahal (1981), for example, describes how the performance of technological products progresses over time. The somewhat stylized result is the well-known smooth S-shaped performance curve. The idea that different types of innovations (incremental and radical) can be distinguished in the development and diffusion of technological systems is widely recognized (Abernathy and Utterback, 1978; Tushman and Anderson, 1986; Tushman and Rosenkopf, 1992; Tushman *et al.*, 1997) and is referred to as the punctuated equilibrium perspective. Based on these conceptual notions, Ortt and

[1] SOU (2007, p.143) questions the use of such composite questions in the CIS (i.e., about regulations and standards), and the lack of clarity of these terms (e.g., nothing is said about the existence of different types of standards or on how they may inhibit innovation). In a similar vein, Swann and Lambert (2010, p.372) reflect that 'inhibiting innovation' in question 8.1 is probably not read as 'preventing' but rather as 'constraining' options – given the research findings.

Schoormans (2004) propose a model in which three phases are distinguished in the development and diffusion of radically new high-tech products: the development, adaptation and stabilization phase (see Figure 1).

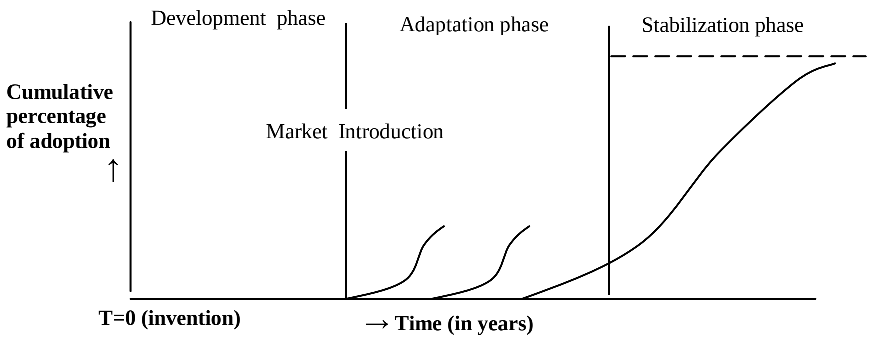

Figure 1: *Phases in the process of innovation and diffusion*

The development phase comprises the period from the invention of a technological principle up to the first application of that principle in a new high-tech product in the market. The invention is defined to be the first time the working of the main components of a product is demonstrated in practice. In many cases, the invention is merely the demonstration of a crude working principle that is far from a marketable product or useful process. The second phase, referred to as the adaptation phase, begins after the first application of the product in practice and ends when the application of the product takes off. After the first application, instead of a smooth S-curve, in practice an erratic process of diffusion may occur (Clark, 1985). The diffusion is often characterized by the periodic introduction, decline and re-introduction of multiple products in multiple small-scale applications, as is illustrated with many telecommunication products and services (Carey and Moss, 1985). These products are produced in relatively small batches. In standard diffusion models the adaptation phase is often omitted although our previous work shows that in 80% of the cases this phase can be distinguished (Ortt, 2010) and lasts about a decade on average. The third phase, referred to as the stabilization phase, begins when the new high-tech product is produced on an industrial scale and the diffusion of the product takes off. This phase ends when product type is almost completely substituted. In this phase, the diffusion of a product most closely resembles an S-curve. Similar phases are distinguished by Agarwal and Bayus (2002) and Tushman and Anderson (1986), however, their phases are specific for certain industries, while our description of the process of development and diffusion is applicable to widely different industries.

The first phase is called development phase because it refers to the development of a marketable product on the basis of the invention. In contrast, innovation refers to the creation of new products, which can happen throughout the entire process. Innovation can refer to the creation of radically new products (during the development phase) and to the creation of incrementally new products (during the adaptation and stabilization phases). The second phase is called adaptation phase because in this phase in a kind of trial and error process, product variants are adapted to meet the needs of specific customer segments. The third phase is called stabilization phase because in this phase the type of product and the customer segments are more or less crystalized and attention focuses on optimizing production, distribution and marketing.

It is important to realize that the pattern is generic but in practice can take different forms. In specific cases of radically new high-tech products the development phase or the adaptation phase does not appear in the pattern. Medicines, for example, often require a long time to develop, but once they pass all development steps the diffusion can take off immediately. In that case, the adaptation phase is omitted from the pattern. Some exceptional inventions can almost directly be developed into a marketable product. An example is dynamite that was introduced within a year after its invention. In that case, both the development and adaptation phase are omitted. Finally, some inventions never make it into the stabilization phase. The mechanical television, for example, was available as experimental product but became outdated before diffusion started. The mechanical television technology was completely substituted by its electronic successor.

In this article we focus on the first two phases of the process. These are also referred to as the pre-diffusion phases. The development phase is important because in this phase the technological principle embedded in the invention is further refined and turned into a marketable product. The adaptation phase is important because in this phase the product is matched with the needs and wants of particular customer segments and the system of complementary products and services is put into practice. We will focus on the effect of pre-existing standards and regulations on the length of these two phases.

2.3 The effect of pre-existing standards and regulations on the process

'Pre-existing standards and regulations' refer to the set of standards, rules, laws and conventions available in the industry *prior to* the development of a radically new high-tech product. That is, these standards and regulations do not specifically target the new product but can be a basis for its further development. Different lines of reasoning may explain why pre-existing standards and regulations might enable or hamper innovation and, accordingly, lengthen or shorten the development phase, i.e. the phase from invention to first introduction. On the one hand, these standards and regulations may contain requirements that have to be met and therefore lengthen the development phase. On the other hand, standards and regulations may also limit the options to be explored during the development phase and thereby shorten it. The net result of these two effects is as yet unclear.

In a similar vein, different lines of reasoning can be followed to argue why pre-existing standards and regulations might shorten or lengthen the adaptation phase, i.e., the phase from an innovation's first introduction up to a product's initial industrial production and large-scale diffusion. On the one hand, standards and regulations might facilitate the process of mutual adaptation of product variants and customer segments, and they might ease interoperability between complementary products and services if they are informative and contain guidance on the design, construction process, application requirements and/or use of the radically new high-tech product. This information would prevent the emergence of competition between alternative designs of the new product and facilitate its use for specific applications. Hence, pre-existing standards and regulations could shorten the adaptation phase. On the other hand, standards and regulations could also hamper this adaptation process if they are incompatible with the new product and its intended use. Hence, pre-existing standards and regulations could also lengthen the adaptation phase.

In sum, there are grounds to argue that pre-existing standards and regulations can both stimulate and hamper innovation, and therefore shorten as well as lengthen the development and adaptation phase, respectively. Pre-existing standards and regulations that can be built upon (and provide initial clarity about the design space, including design requirements) and are well-aligned with the new product and its application context are most likely to have a stimulating effect and shorten the development and adaptation phase.

Hypothesis 1: Pre-existing standards and regulations that can be built upon in developing the new product will shorten the development and adaptation phase.

For certain products, pre-existing standards and regulations are likely to be more important than for others. In particular, if new products are to operate within technological systems that have a high degree of technical interrelatedness and interdependencies, an additional layer of complexity is involved. We expect that for such products the effect of standards and regulations on the length of the adaptation and development phase is likely to be more prominent. That is, we view "interrelatedness of a technological system" as a variable that moderates the effect of pre-existing standards and regulations on the length of the development and adaptation phase. Furthermore, we expect that for product innovations based on more radically new technologies, pre-existing standards and regulations will have a more prominent effect.

Hypothesis 2: Increased interrelatedness of the technological system to which the product belongs, will reinforce the effect of pre-existing standards and regulations on the length of the development and adaptation phase.

Hypothesis 3: Increased technological radicalness in the product will reinforce the effect of pre-existing standards and regulations on the length of the development and adaptation phase.

All three hypotheses are shown in Figure 2. Hypothesis 1 indicates a direct effect from the pre-existing standards and regulations on the length of the development and adaptation phase. Hypothesis 2 and 3 indicate that the strength of the previous effect depends on two moderating variables, i.e. the interrelatedness of the technological system and the radicalness of the technology involved.

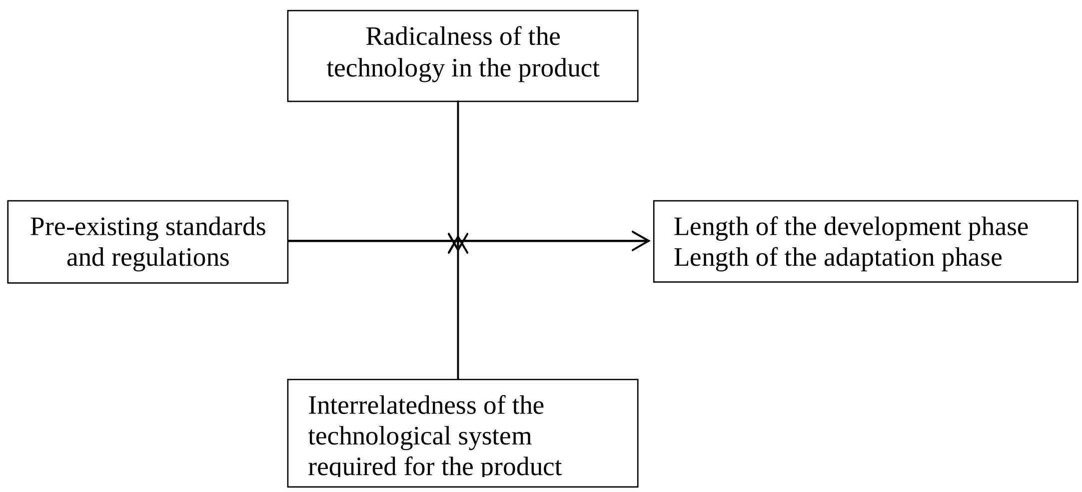

Figure 2: *Model of how pre-existing standards and regulations in combination with two moderating variables determine the length of the development and adaptation phases.*

3. Method

3.1 Data gathering

To explore the impact of pre-existing standards and regulations on the innovation and diffusion process, we selected fifty cases of radically new high-tech product. Because a more heterogeneous set of cases promised to deliver richer insights, cases were chosen that differ with respect to industry sector and time of introduction. The selected industries were (1) 'Materials', including chemicals, materials and metals; (2) 'Pharmaceuticals', including medicine and healthcare equipment'; (3) 'Telecommunications, including telecommunication products and services, and (4) 'Electronics', including electronic components and products. These industries differ strongly in the way new products are developed and introduced. For example, the (relative) length of their development and adaptation phases differs significantly (Ortt et al., 2009). Regarding the time of introduction, to avoid anachronism, cases were selected based on timeslots from the mid-nineteenth century onwards. This period can reasonably be argued to be a starting point for many industries. Telegraphy, one of the first forms of electronic telecommunication, was applied from then on (Huurdeman, 2003). In the same period, semi-synthetic materials such as nitrocellulose started to be systematically investigated. These materials are the precursors of modern chemical industry (Friedel, 1983). Similar arguments apply to pharmaceuticals and electronics.

For each industry we identified radically new high-tech products. Of these about a dozen cases per industry were selected for further analysis. For each case we did an extensive literature search. We systematically searched for sources using several case-related keywords. To start with, a wider search was done by combining different names for the same product with the keyword 'history'. More specific searches followed that combined the different product names with the keywords 'invention', 'introduction', 'diffusion', 'innovation' and 'development'. From these search results, a selection was used for further study.

In total, we examined fifty cases. Per case we analysed and cross-checked multiple sources to assess the approximate year of invention, introduction and the start of industrial production and large-scale diffusion. These three hallmarks define the development and adaptation phases, the lengths of which are hypothesized to be affected by pre-existing regulations and standards. The timeline was further used to analyse the actors and factors relevant for the development and diffusion of the radically new product innovations. This resulted in a set of chronically ordered case descriptions. The case-studies cover unique elements for each case, but we also decided to gather similar data for the cases in order to compare them. To systematically analyse all cases, we used the first 25 cases to form a list of questions that represented characteristics of the new high-tech product, its competitors, the characteristics of the companies involved, and the relevant market factors and actors during the development and adaptation phase. Standards and regulations were found to be important market factors and that is why we added these aspects in our analysis. For all of the aspects alternative answers were assessed, enabling coding and further analysis of the multi-case study results. After this analysis tool was completed the set of 50 cases was analysed.

3.2 Variable formation

Pre-existing standards and regulations

For each case, the relevance of pre-existing standards and regulations was examined, described and coded. The procedure was as follows: Two experts were asked to read the case description and score the two questionnaire items on the pre-existence of case-related standards and regulations (see the box below). One of the experts typically had expertise in the case-related industry area. The other expert was held constant for all cases in order to ensure a consistent assessment across cases. In most of the cases, the expert evaluations coincided; yet in some cases discussion was needed to reach agreement.

Operationalization of pre-existing standards and regulations
The availability of pre-existing standards on different levels (e.g., OSI for telco system) with regard to diverse aspects of the system that can be used when the technology is applied. 1. Very large 2. Large 3. Not large or small 4. Small 5. Very small The availability of pre-existing regulation that can be used when the technology is applied. 1. Very large 2. Large 3. Not large or small 4. Small 5. Very small

The item correlation was very high (r=0.76; p=0.000). The items formed a very reliable scale (alpha=0.86), which is important as this scale was used to assess whether pre-existing standards and regulations have an effect on the development and adaptation phase.

Interrelatedness of the technological system required for the product

Next we formed two subgroups of cases based on the 'interrelatedness of the technological system required for the product'. This variable was based on three questions (items), with answers from 1-5. The items formed a very reliable scale (alpha=0.92).

Operationalization of the interrelatedness of the technological system required for the product
The technology can be classified as: 1. A singular material (like Kevlar). 2. An alloy or a mixture of materials or substances (like memory metal). 3. A simple assembled component or product (like bolt and nut, ski, can, paperclip). 4. A complex assembled component or product (like a chip or a car). 5. A system consisting of a combination of many products and services (like a telecommunication or railway system). Physical network requirements for large-scale application of the technology. 1. Very small (no network requirements). 2. Small (like compatibility with some peripherals or tools). 3. Not large or small (like dealer/service network with special tools for specific cars). 4. Large (like a hardware software requirements for PC or video). 5. Very large (like large-scale infrastructure for GPS, telecom or transport). Degree to which compatibility of the technology with complementary technologies is important for wide-scale diffusion. 1. Very unimportant (technology can function completely stand-alone). 2. Unimportant (technology should be compatible with some peripherals). 3. Not (un)important 4. Important (technology can function standalone without a network but should be compatible with some peripherals and/or software). 5. Very important (technology should be compatible with a large system consisting of a network, peripherals, other appliances, software, and so on).

Radicalness of the technology in the product
The 'radicalness of the technology in the product' refers to the degree in which the *functionality* provided by the technology is considered as new in the market, it refers to the degree in which the *product type* based on the technology is considered as new in the market and it refers to the degree in which the technology is different from closest alternative technology available in the market.

The radicalness of the technology is assessed at the time the first product based on the technology is introduced. We formed two subgroups of cases based on the 'Radicalness of the technology in the product'. This variable was formed by three questions (items), each item ranging from 1-5. The items formed a reliable scale (alpha=0.79).

Operationalization of the radicalness of the technology in the product innovation

The newness (i.e. newness to the world) of the functionality provided by technology <u>at the time of introduction</u>. The functionality refers to the function that is performed (like moving/transport, communication, generate or transform energy, and so on).

1. Standard, well-known functionality (clothing: from silk and cotton to nylon).
2. Known functionality with minor extensions (storing data: from gramophone to cd).
3. Known functionality, major extensions (e.g. from classic to digital photography).
4. Known functionality changed fundamentally (e.g. from gramophone to interactive cd).
5. Totally new functionality (telecommunication: from letters to telegraphy to telephony)

The newness (i.e. newness to the world) of the product incorporating the technology <u>at the time of introduction</u>. The term 'product' can also refer to a component or process.

1. Same product (new product in terms of price/performance but not in form).
2. Renewed product (new product like a *larger* propeller-powered airplane).
3. New product (product is renewed considerably, like the first jet-powered air-plane in comparison to airplane with propellers).
4. New product type (new type of product in existing category, like the first helicopter as a new type of airplane).
5. New product category (new product category is formed, like the first airplane).

In comparison to the closest alternative technology available before the first introduction of the new technology, the new technology is

1. Far more simple.
2. More simple.
3. As simple or complex.
4. More complex.
5. Far more complex.

Length of the development and adaptation phase
Finally, the lengths of the development and adaptation phase were assessed in terms of the time-interval (in years).

3.3 Analyses

Two analyses were carried out. The first one focused on the relationship between "the availability of pre-existing standards and regulations", on the one hand, and "the length of the development and adaptation phase", on the other. This relationship was analysed using both parametric and non-parametric correlations. Parametric correlations (Pearson's r) are often used for five-point scales. A parametric correlation assesses an effect assuming that the variables are interval-scaled and the relationship is linear. Non-parametric correlations (Kendall's tau and Spearman's rho) assume that the variables are ordinal-scaled (which is in fact the case) and are also able to detect non-linear relationships.

The second analysis further scrutinized the strength of the above correlations by taking into account the possible effect of the two moderating variables: "Interrelatedness of the technological system required for the product" and "Radicalness of the technology in the product".

These variables were both formed by adding up the scores of the three 5-point scales. Two groups of about equal size were formed for each moderating variable. For the first moderating variable, products based on a technological system with a relatively large and small degree of interrelatedness were distinguished. For the second moderating variable, products based on relatively radical and non-radical technologies were distinguished. For both groups we repeated the first analysis, assessing the correlation between "the availability of pre-existing standards and regulations", and "the length of the development and adaptation phase".

4. Results

4.1 Overview of the cases

The full set of fifty radically new high-tech products is shown in Table 1 below.

Table 1: *Cases of radically new high-tech products.*

↓ Time of introduction	Industry →				
	Chemicals, metals & materials	Medicines	Telecommunication equipment	Electronic equipment	
1839-1900	- Nitroglycerine - Rayon - Celluloid - Gun cotton - Dynamite	- Aspirin - X-ray	- Telegraphy - Telephony	- Phonograph	10
1901-1925	- Cellophane - Monel - Bakelite	- Salversan - Insulin	- Radio telephony - Radio broadcast	- Magnetic recording - Vacuum tube	9
1926-1950	- Nylon - Teflon - PET - PVC - DDT	- Penicillin	- Electronic television	- Microwave oven - Fluorescent light	9
1951-1975	- Kevlar - Dyneema - Nitinol	- Paracetamol - Methylphenidate - Polio vaccine - Minoxidil	- GNSS (GPS)	- Transistor - Video Cassette Recorder - LED - Microprocessor - LCD - Plasma display	14
1976-	- Twaron	- Viagra - SSRI (Prozac)	- Bluetooth - SMS - Cellular mobile telephony	- Computer mouse - DVD	8
Total	17	11	9	13	50

For the 50 cases in the sample, the average length of the development and adaptation phase is about 12.5 and 7.5 years, respectively. That is, the time required for radically new high-tech products to start diffusion on a large scale after its invention is roughly two decades.

4.2 The impact of pre-existing standards and regulations

To start with, we analyzed the relationship between "the availability of pre-existing standards and regulations" and "the length of the development and adaptation phase" using parametric and non-parametric correlation methods (see Table 2).

Table 2: *Correlation between pre-existing standards and regulations and the length of phases*

	Development phase			**Adaptation phase**		
	Pearson correlation	Spearman's rho	Kendall's tau	Pearson correlation	Spearman's rho	Kendall's tau
Pre-existing standards and regulations	-0.006 p=0.483 N=50	-0.147 p=0.154 N=50	-0.105 p=0.163 N=50	0.299 **p=0.018 (*)** N=50	0.323 **p=0.011** N=50	0.227 **p=0.017** N=50

(*) Significant correlations are indicated in boldface

The results in Table 2 show that pre-existing standards and regulations are not related to - and therefore have no clear effect on - the length of the development phase. This finding is consistent for all three types of correlations. In contrast, a significant relationship is found between 'pre-existing standards and regulations' and 'the length of the adaptation phase'. That is, hypothesis 1 is confirmed for the adaptation phase but not for the development phase.

4.3 The moderating effect of interrelatedness and radicalness

To further investigate the relationship between 'pre-existing standards and regulations' and 'the length of the adaptation phase', we included two moderating variables, interrelatedness and radicalness of the technological system in which the high-tech product fits. For both variables, cases were divided in groups with low and high values (see Table 3).

Table 3: *Case groupings based on interrelatedness and radicalness of the technological system.*

	Relatively low score on radicalness		**Relatively high score on radicalness**		
Relatively low score on interrelated-ness	Kevlar Nylon Bakelite Dyneema Magnetic recording (wire) Dynamite Cellophane PVC PET Rayon SSRI	Monel Teflon Nitroglycerine Celluloid Paracetamol DDT Twaron Polio medicine Minoxidil Salversan	Nitinol Aspirin Penicilin	Viagra Methylphenidate Insuline	27
Relatively high score on interrelatedness	DVD Bluetooth Transistor SMS	LED Fluorescent lamp Guncotton	GNSS Microwave oven Cellular mobile telephony (Electrical) Telegraphy Plasma tv VCR Electronic television X-Ray	Computer mouse Vacuum tube Telephony Microprocessor LCD Radio broadcasting Radio telephony Phonograph	23
	28		22		50

Cases that are relatively low on interrelatedness are mostly coming from two industries: Chemicals, metals & materials and Medicines. Cases that are relatively high on interrelatedness are mostly coming from the telecommunication and electronic industries. For the other moderating variable, radicalness, a similar division across industries cannot be found. This means that all of the industries have cases that are both high and low on radicalness.

Our next step was to look at the relationship between 'pre-existing standards and regulations', on the one hand, and 'the length of the adaptation phase', on the other, for different values of the moderating variables.

Table 5: *Correlation between 'pre-existing standards and regulations' and 'the length of the adaptation phase' for cases with low and high values on the moderating variables*

Correlation between pre-existing standards and regulations and the length of the adaptation phase	Products in systems with a relatively low score on interrelatedness	Products in systems with a relatively high score on interrelatedness
Pearson correlation Spearman's rho Kendall's tau	0.076; p=0.353; N=27 0.024; p=0.453; N=27 0.016; p=0.457; N=27	0.512; **p=0.006**; N=23 0.643; **p=0.000**; N=23 0.463; **p=0.002**; N=23
	Products with a relatively low score on radicalness	Products with a relatively high score on radicalness
Pearson correlation Spearman's rho Kendall's tau	0.216; p=0.270; N=28 0.214; p=0.275; N=28 0.160; p=0.273; N=28	0.389; **p=0.074**; N=22 0.466; **p=0.029**; N=22 0.322; **p=0.052**; N=22

The results in the second row are consistent: for products in a technological system with relatively low interrelatedness no effect of pre-existing standards and regulations is found; whereas for products in a technological system with a relatively high interrelatedness a very large and significant effect is found.

The results in the last row show that for products with relatively low scores on radicalness no effects of pre-existing standards and regulations are found; whereas for products with relatively high scores on radicalness a modest effect is found (almost significant effect for the Pearson correlation and Kendall's tau and significant effect using Spearman's rho).

5 Why do pre-existing standards and regulations shorten the adaptation phase and not the development phase?

The goal of this section is to illustrate why pre-existing standards and regulations can shorten the adaptation phase while they do not have an effect on the length of the development phase. Or conversely: To illustrate why a lack of pre-existing standards and regulations can lengthen the adaptation phase while they do not have an effect on the development phase.

We selected two completely different cases, cellular mobile telephony and plasma screen. Both cases are invented in the early 1960s and both are relatively radical and part of a relatively inter-related technological system. Prior to the invention and introduction of cellular mobile telephony, many pre-existing standards and regulations were available. In line with the results from the statistical analysis, for this case the adaptation phase is relatively short. In contrast, prior to the invention and introduction of plasma screens a limited number of pre-existing standards and regulations was available. In line with the results from the statistical analysis, for this case the adaptation phase is relatively long.

Table 6: *Pattern of development and diffusion for two cases*

Name	**Invent**	**Intro**	**Start large-scale**	**Length development phase**	**Length adaptation phase**	**Industry**	**Pre-existing standards regulations**
Mobile telephony	1962	1983	1983	21	0	Telecom	Many
Plasma tv	1964	1971	2001	7	30	Electronics	Few

[1] The score can range between 2 and 10. A score 2 refers to the situation that many pre-existing standards and regulations are available, a score 10 refers to the situation that almost no standards and regulations are available.

5.1 Mobile cellular telephony (many pre-existing standards and regulations)

In the history of telecommunication many related yet different systems of mobile telecommunication are developed, ranging from radio telegraphy, telex to radio broadcasting (Huurdeman, 2003). Mobile cellular telephony is a particular technology that can be defined in terms of its functionality:

1. Two-way voice contact (instantaneous and interactive)
2. Mobility (car or pedestrian can carry mobile unit)
3. Interconnection with wired telephone system (ability to call normal telephones)
4. Switching (ability to connect to a particular telephone)
5. Roaming /hand over (more seamlessly from one cell to another during contact)

The case of the cellular mobile telephony is characterized by a pattern of development and diffusion with a long development phase (21 years) and an extremely short adaptation phase (0 years). Many factors are found to be important for explaining this particular pattern. We are particularly interested in the effect of pre-existing standards and regulations.

Why a relatively long development phase?

After the first demonstration of the cellular mobile telephony system in 1962, it took a long time to introduce it in the market in 1983. At first sight it seems logic that a long period is required for introducing a complex system that requires an extensive infrastructure. However, for the entire dataset of 50 cases we found no direct relationship between the length of the development phase and the adaptation phase on the one hand and the complexity of the technology or the required infrastructure on the other hand. This means that complexity and infrastructural requirements are generally not the reason why either the development phase or the adaptation phase will become relatively long. This general finding seems to be confirmed for the particular case of mobile cellular telephony.

We found several other reasons why the development phase for cellular mobile telephony took so long. In short, the perceived interests and the leadership of the incumbent telecommunication company (AT&T) in combination with the influence of the FCC responsible for allocating scarce spectrum delayed the introduction of mobile telephony considerably. These reasons will be explored in more detail.

AT&T, although it had all the resources to introduce mobile cellular telephony, was not eager do to so. Several authors describe this lack of eagerness. “AT&T had no incentive to develop a wireless system of communication that would effectively compete with what was arguably the best landline telephone system in the world” (Gershon, 2003, p.177-8). “The leadership of the new AT&T organization simply never saw cellular telephony as a competence they owned and could exploit" (King & West, 2002, p. 197).

Several institutions blocked a swift introduction of mobile cellular telephony. "(..) the FCC contributed to the delay by failing to grant the necessary spectrum in order to kick-start the industry. This, in turn, limited the number of mobile customers and thus prevented any new service from fully developing. Some observers have argued that the FCC's lack of responsiveness delayed the start of cellular technology by as much as 10 years." (Gershon, 2003, p. 178). The reason that FCC was reluctant to grant spectrum was its scarcity. Television broadcast, emergency service such as the police and the fireworks and the military forces all required part of the spectrum. On top of that, spectrum for private and industrial use of mobile telecommunication was also requested next to the public use. Furthermore, FCC was reluctant to grant AT&T a monopoly position. Davis (1988) describes how the FCC because of that reason required the manufacturing and service providing part of AT&T to break up in 1974. So, institutional constraints (West, 2000) together with a lack of leadership by the AT&T management (King & West, 2002) delayed the introduction of mobile cellular telephony.

It is interesting that, at the time when spectrum was allocated, a strong market need stimulated a swift process of building up. As a result large-scale diffusion appeared almost directly after introduction of the service meaning that the adaptation phase was left out.

5.2 Plasma screens (few pre-existing standards and regulations)

In contrast to cellular mobile telephony, the case of the plasma screen is characterized by a few pre-existing standards and regulations. The pattern of development and diffusion shows a relatively short development phase (7 years) and a relatively long adaptation phase (30 years). Several factors can be mentioned to explain this pattern.

"Looking back, the period from the initial invention of the plasma panel in 1964 until the first product delivery in 1971 was a remarkably short time" (Weber, 2006, p. 271). This period from 1964 to 1971 could have been even shorter when a patent was granted earlier than 1971. This is remarkable because the technology, at the time of its invention was fragile and not ready to be introduced. "The devices made by the University of Illinois proved the fundamental concepts, but they were too fragile for commercial products" (Weber, 2006, p. 270). This case shows again that complexity of a technology is hardly the reason for a long development phase.

The period from 1971 to 2001 required to enter the phase of industrial production and large-scale diffusion, is exceptionally long. "The technology struggled for decades and faced many challenging problems" (Weber, 2006, p. 268). Competition between alternative plasma displays might be an important factor (Weber, 2006). Standardization could have possibly removed that factor and thereby reduced the length of the adaptation phase. In addition, competition with another technology, the LCD-screen, proved an important factor (Uchiike, 2002; Mently, 2002). "Monochrome plasma displays acquired a reputation for reliability and later for low cost, but the market for monochrome displays was generally ceded to LCDs in the 1980s" (Mently, 2002, p. 456).

5.3 Tentative conclusions from the two cases

The goal of the description of the two cases, cellular mobile telephony and plasma screens, is to explain our finding that pre-existing standards and regulations are related to a relatively short adaptation phase, while they are not having a similar effect on the development phase. These cases do provide a tentative explanation. Institutions in general, and standards and regulations in particular are a considerable hurdle in the development phase, but they can speed up the diffusion process.

Especially in the case of mobile telephony, the existing standards and regulation were all geared towards existing (tele)communication services like television broadcasting and mobile communication for military forces and emergency services. It took a while to overcome that barrier, but once the standards and regulations particularly for the new cellular technology were in place it proved to speed up the diffusion process.

In the case of the plasma screen, regulation and standardization were less important. The first products were introduced very quickly, but the competition among alternative types of plasma screens and with other technologies such as the LCD-screen slowed down diffusion after the first market introduction. As a result, the adaptation phase became relatively long. The two cases indicate that (pre-existing) standards and regulations are a kind of hurdle during development but, once there, stimulate diffusion.

6. Conclusion and Discussion

On average, for a wide range of radically new high-tech products, pre-existing standards and regulations are associated with a short time interval from first market introduction to large-scale diffusion and industrial production (referred to as the adaptation phase). A similar effect is not found for the time interval between the invention and the first introduction of a radically new high-tech product (referred to as the development phase). So, pre-existing standards and regulations have no overall effect on the development but can have a shortening effect on the diffusion of new high-tech products.

The direct effect on the length of the adaptation phase is moderated by two variables: the interrelatedness of the technological system involved and the radicalness of the technology in the product. The effect of the second moderating variable is weaker. In short: the effect of pre-existing standards and regulations on the length of the adaptation phase is very strong for products based on interrelated and radically new technological systems.

Methodologically, these results indicate a strong and consistent effect. The direct effect of pre-existing standards and regulations on the length of the adaptation phase is significant. This is remarkable, especially if one realizes that the variable ‘interrelatedness of the technological system’ has no direct effect on the length of this phase. This interrelatedness, in practice meaning that extensive infrastructural arrangements and complementary product and services are required for the product, would seem an obvious cause of a long development and adaptation phase, but again, that effect is not found. The effect of pre-existing standards and regulations is also remarkable taking into account the relatively small sample size and the heterogeneous character of the cases. In such a situation, the statistical power to detect relationships is relatively small and only strong relationships can be detected. The results regarding the moderated effect further confirm the significance of pre-existing standards and regulations.

Scientifically, our starting point was Swann and Lambert’s (2010) conclusion that the question whether standards enable or constrain innovation contains a false antithesis. The explanations offered by King (2006) and Swann and Lambert (2010) indicated the enabling *and* constraining influence of pre-existing standards and regulations. Our work further refines this notion by indicating that pre-existing standards and regulations can have different effects in subsequent phases of the pattern of development and diffusion. We found that pre-existing standards and regulations are related to a relatively short adaptation phase while a similar effect for the development phase was not found. Furthermore these effects are found to depend on the characteristics of the technological system, in particular its interrelatedness and radicalness.

But why do pre-existing standards and regulations primarily have an effect on the length of the adaptation phase rather than the development phase? In order to interpret our statistical findings we explored in more detail what happened in two selected cases, mobile cellular telephony and plasma screens. We found, for the mobile telephony case, that regulations and standards in combination with the interests of incumbent companies, can significantly delay market introduction of new systems. We also found, for the case of plasma screens, that a lack of these regulations and standards may allow swift introduction, but a long adaptation phase can then be expected because the lack of standardization will lead to a de facto battle between competitive technologies. Further research is needed to verify these notions for a wider set of cases.

The managerial and societal implications of the finding that pre-existing standards and regulations shorten the adaptation phase are significant. On average this phase lasts long – in our sample the average duration of the adaptation phase is 7.5 years - and can be a disastrous period for pioneering companies attempting to commercialize their radically new product. Many companies fail in this phase (Ortt, Shah and Zegveld, 2007), especially pioneering companies. The high failure rate among pioneering companies is referred to as ‘the burnout of the pioneers’ (Olleros, 1986). For radically new high-tech products this failure rate is significantly higher than for companies that introduce incrementally new products (Pech, 2003; Tellis and Golder, 1996). Societally a long adaptation phase is expensive and creates much uncertainty about and delay in the application of valuable innovations.

Furthermore, the finding that the benefits from pre-existing standards and regulations are most significant for products requiring interrelated and radically new technological systems deserves further scrutiny. Our results indicate that pre-existing standards and regulations have a strong effect on the length of the adaptation phase in the telecommunication and electronics industry. Additional analysis shows that the need for compatibility largely explains these results. For products based on non-interrelated technological systems compatibility with complementary products and service is significantly less important than for those based on interrelated technological systems. This implies that the need for and presence of compatibility standards, which are most common in the telecommunication and electronics industry, may play a determining factor for the length of the adaptation phase. Follow-up research is needed to further explore the different effects of different types of standards on innovation.

7. Future research

Our findings offer several avenues for future research. First of all, we want to further explain why pre-existing standards and regulations shorten the adaptation phase. Moreover, also the development phase deserves our interest. Our results indicate that the development phase is rather long (for our sample the average length of this phase is about 12.5 years). Apparently pre-existing standards and regulations do not shorten this period. Our preliminary case-study findings deserve further analysis by adding cases.

Second, while cross-checking our findings we found that the shortening effect on the length of the adaptation phase was not only found for ‘standards and regulations’ together but also for ‘standards’ separately. We therefore propose a follow-up study that refines the variables and their interrelations to increase insight into the impact of standards on innovation. Thus, the difference between pre-existing regulations and standards and their distinct effect should be further examined. Where standards are concerned, we recommend differentiating between categories of standards, that is, between product (descriptive) and performance standards; measurement standards, minimum/maximum requirements standards, classification standards and compatibility standards. Of interest is whether distinct categories of standards have a different impact on the development and diffusion of radically new high-tech products.

Third, the previous provides a stepping stone for research on the key question ‘Does the effect on innovation depend on the timing of committee-based standardization?’ and for contributing to the debate about standardizing too soon or too late. It would entail expanding the current research from pre-existing standards to standardization efforts during the innovation trajectory, that is, during the development, adaptation, and stabilization phases. These phases roughly coincide with anticipatory standards (agreed on in the development phase), enabling standards (agreed on during the adaptation phase), and retrospective standards (agreed on during the stabilization phase). This should be cross-checked with the type of innovation involved (Egyedi and Sherif, 2010). Does the effect of timing in standardization depend on the kind of innovation at stake?

Acknowledgements

We sincerely thank Mostafa Sherif and the three anonymous SIIT reviewers for their comments on this paper and Peter Swann for helping us with several important sources.

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