Roadmapping for innovation management: Evidence from Pirelli

Abstract

Despite the growing interest of practitioners and scholars in technology roadmapping (TRM), our knowledge regarding how TRM can be embedded into the overall innovation process of a firm and used to enhance this process is relatively limited. This study aims to fill this gap. We describe an action research project conducted with Pirelli and the innovative approach to TRM this company developed during the 2010s to cope with the increasing complexity and dynamism of the tire industry. We show that TRM is currently fully integrated into the firm's R&D activities and contributes to increasing the effectiveness of new product development. TRM supports the systematic gathering, sharing, and elaboration of information across the different functions and business units of Pirelli from basic research to the commercialization of new products.

Keywords: Product and technology roadmaps; information gathering; new product development; innovation management; R&D management

1. Introduction

Since the early 1980s, product and technology roadmapping (TRM)—a systematic, formalized approach to technology and product development—has become quite popular among R&D and innovation managers (Phaal et al., 2010; Kerr et al., 2012; Kostoff et al., 2004). TRM has been used in several leading companies to explore the coevolution of technologies, products, and markets and to anticipate the resources required for future success (Albright and Kappel, 2003; Rinne, 2004).

In the early 2000s, however, the increasing volatility of the business environment (in particular, the quick pace of globalization, regulation, and technological and social change) has made technology planning and innovation management more difficult. Rapid change requires flexible strategies and continuous adaptation, which are characteristics that are seldom associated with formal planning approaches (Iansiti, 1998; O'Reagan and Ghobadian, 2005; Phaal et al., 2006).

The challenge of managing innovation under growing uncertainty has encouraged the rethinking of traditional approaches to technology and product development, including TRM (Noh et al., 2017). Scholars and practitioners have noted that the main role of TRM should be not the creation of long-term plans but rather the establishment of a continuous process that supports the coordination and execution of the overall innovation efforts of a firm (Phaal et al., 2004; Radnor and Probert, 2004). However, thus far, our knowledge regarding the relationship between TRM and new product development in dynamic environments is relatively limited.

The main objective of this paper is to bridge this gap. We explore how R&D managers can fully integrate TRM into the overall innovation activities of corporate organizations and enhance the impact of TRM on such activities. Our research setting is Pirelli and the turbulent tire industry. We describe the action research project that was carried out in this company during the 2010s and how this project enabled the design and introduction of an innovative approach to TRM.

This paper contributes to our knowledge about R&D and innovation management in two main areas. First, it investigates how companies' TRM practices have evolved in a world of rapid change. Second, it improves our understanding of the merits of TRM and its role in new product development.

The paper is structured as follows. Section 2 briefly reviews the relevant literature on product and technology roadmaps. Section 3 illustrates our research setting. Sections 4 and 5 focus on TRM activities in Pirelli and their outcomes and impact on the performance of this firm. Finally, sections 6 and 7 outline the general insights and lessons for R&D and innovation management drawn from this case.

2. Theoretical background and framework

2.1. Technology management and technology roadmapping

Technology management is a key task of R&D managers in charge of sustaining the long-term success and growth of their organizations (Calantone et al., 2003; Dodgson, 2000; Song et al., 2011). Since the 1980s, TRM has been one of the most popular methods for supporting this task (Kappel, 2001).

The pioneering developer of TRM in the private sector has been Motorola in the mobile communication and semiconductor industry (Richey and Grinnell, 2004), followed by other leading companies in technology-intensive industries (e.g., consumer electronics and aerospace), such as Philips Electronics (Groenveld, 1997) and Lucent Technologies (Albright and Kappel, 2003).

A roadmap is a graphical representation of the coevolution over the course of time of technologies, products and markets. Precisely, Phaal et al. (2004, p. 10) define a roadmap as “a time-based chart, comprising a number of layers that typically include both commercial and technological perspectives. The roadmap enables the evolution of markets, products and technologies to be explored, together with the linkages and discontinuities between the various perspectives.” The process through which roadmaps are built is typically called “roadmapping” (Phaal et al., 2004). This technique involves a series of meetings and workshops that bring together managers from different functions and external experts who work together to identify and develop the attributes for the nodes and links of the roadmaps. In the most common approach, roadmapping is basically a subjective process that relies on expert judgments or other forecasting techniques, such as Delphi or brainstorming, to collect and elaborate insights that will ultimately be embedded in the roadmaps. Alternatively, the computer-based approach uses algorithms, such as computational linguistics and citation analyses, to search large textual databases related to science, technology, engineering, and products (Kostoff and Schaller, 2001).

2.2. TRM and new product development in turbulent environments

Scholars and practitioners initially emphasized that the main benefits of TRM for innovation managers are related to the anticipation of emerging customer needs, product categories, and product features and the technologies required to address these needs and features (Choi et al., 2013; Lee et al., 2011; Li, 2009; Oliveira and Rozenfeld, 2010). Forecasts regarding future technologies, products, and markets enable the optimization of R&D investments (Garcia and Bray, 1998).

However, since the early 2000s, the growing pace of change in the business environment has made the task of anticipating future customer needs considerably more challenging, thus encouraging the design of new approaches to technology and innovation management, particularly a rethinking of the role of roadmapping (Arman et al., 2017; Lee et al., 2012; Simonse et al., 2015). While scholars and practitioners initially emphasized the outputs of roadmaps, i.e., forecasts about future technologies and products, more recent contributions have focused on the outcomes of roadmapping, i.e., the benefits stemming from the roadmapping process (Kerr et al., 2012; Vecchiato, 2015). These benefits consist of the enhanced capability to sense, seize, and respond to changes in technologies and customer needs in a more timely manner rather than in the knowledge of these changes ex-ante. According to Phaal et al. (2004, p. 23), "many of the benefits of roadmapping are derived from the roadmapping process, rather than the roadmap itself. The process brings together people from different parts of the business, providing an opportunity for sharing information and perspectives and providing a vehicle for holistic consideration of problems, opportunities and new ideas." Thus, Radnor and Probert (2004) argued that organizations must demonstrate long-term commitments to roadmaps by conceiving and implementing them as a continuous process that monitors external changes and updates the roadmaps.

The growing attention to the process of TRM is consistent with recent studies in the mainstream innovation literature, which shifted the focus of attention from the resources and capabilities required for new product development to the practices and activities needed to support innovation (Bagno et al., 2017; Berkhout et al., 2010; Harmancioglu et al., 2007; Lao et al., 2010; Tidd and Thuriaux-Aleman, 2016). Specifically, over the past decade, scholars have diligently explored the overall innovation process of a firm, i.e., the 'innovation management model', which structures the execution of new product development and aims to enhance its effectiveness (i.e., rate of success of new products) and efficiency (i.e., innovation output – measured as new product sales or profits – divided by innovation input – measured as R&D or new product development costs).

In their extensive literature review, Bagno et al. (2017) identified 16 different innovation management models that have been proposed over time by scholars; among these models, Cooper's (2003; 2008) stage-gate model is particularly popular. This model shares the same conceptual premise as other funnel models that emphasize the gradual selection of new project ideas (Schultz et al., 2019) by basically defining the innovation processes as a series of stages encompassing the initial idea generation stage, the subsequent idea scoping stage, the business case building stage, the development stage, the testing and validation stage, the launch stage, and the final post-launch review stage. Each stage comprises a set of required or recommended best-practice activities, including information gathering, information analysis, and elaboration of deliverables. Every stage is followed by a gate, where a go/kill decision is made regarding whether to continue to invest in the new product development project. While the stage-gate model has been successfully adopted by several leading firms, these firms also provided evidence regarding the essential conditions for increasing its benefits and using it as an effective blueprint for innovation management. These conditions include the reliability of the information gathered during each stage, the diligent analysis of this information, and strong organizational design and leadership (Cooper, 2019).

The growing emphasis on the process of TRM and, contextually, the increasing attention to the overall innovation process of corporate organizations have relevant implications for research. Although scholars have noted the capability of TRM to improve the management of innovation and the effectiveness of new product development, our knowledge regarding how TRM concretely contributes to such effectiveness and how this contribution can be optimized is limited. In particular, we know very little about how TRM has evolved since the early 2000s to match the increasing pace of change in the business environment. Recent works have explored the design and use of roadmaps in research centers, public governmental bodies, state-owned enterprises and small- and medium-sized enterprises (SMEs) (Gershman et al., 2016; Jeong and Yoon, 2015; Lee et al., 2015; Loyarte et al., 2014); however, there is no longitudinal study exploring the use and outcomes of TRM in corporate organizations.

Thus, there is an important opportunity to develop a more complete and rich understanding of TRM and its role in innovation management. This paper seizes this opportunity by addressing the following twofold research question: *How can R&D managers seamlessly integrate TRM into the overall innovation process of their firm? How can R&D managers use TRM to enhance the effectiveness of this process?*

3. Research setting: Pirelli and the tire industry

Our research setting is a major multinational company that recently adopted TRM to cope with the growing dynamism of its industry. Specifically, the findings of this paper are based on an action research project that the authors conducted with Pirelli (Adler et al., 2003; Coughlan and Coghlan, 2002).

Pirelli is a global tire manufacturer focusing on the high-end market segment, which targets the “prestige” and “premium” customers of the automotive and motorcycle industries. Consistent with such a strategic focus, Pirelli has devoted considerable efforts to R&D with the aim to continuously expand its product range and match the changing needs of its demanding customers. R&D activities address all main business units of the company, i.e., car and moto, and all main stages of product development, i.e., predevelopment and research, materials development, process development, and testing. By the end of 2019, Pirelli’s R&D activities involved approximately 1,800 employees worldwide with main centers located in Milan (headquarters), Germany (close to the leading carmakers in the premium segment), and Brazil. Their R&D investments amounted to a yearly average of approximately 6.5% percent of the premium sales. The company currently has more than 6,500 active patents.

Pirelli also has a longstanding tradition in racing competitions. In particular, the company has been the Formula One single tire supplier since 2011, and this partnership was renewed in 2018 for another four-year term until 2023. Such a racing sponsorship created severe challenges in terms of technological innovation; in accordance with FIA (Fédération Internationale de l'Automobile) regulations, Pirelli had to design and deliver several different types of tires for both dry and wet surfaces. Over time, all these sets had to match increasingly more demanding specifications in terms of resistance to overheating and high energy loadings and consistency over the course of a stint by adapting to different surface conditions and providing different balances of performance and durability. The partnership with the Formula One racing teams led Pirelli to develop a wide range of new R&D skills from raw materials to simulation models.

3.1. Tire industry: Increased turbulence and challenges for R&D management

Tires represent a critical item for vehicles and particularly road safety since they are the only point of contact between the vehicle and the road. As such, tires are used in a wide range of conditions (temperatures, road conditions and surfaces, driving styles and vehicle characteristics). Especially in the case of racing competitions and performance cars, tires are exposed to very demanding challenges due to the forces generated by the vehicles' engines and by temperature and wear. Today, tires are the component of the automotive that is affected by the highest number of governmental regulation requirements. Critical product features encompass braking and handling behavior, contribution to vehicle fuel consumption, tire mileage, noise generation, and extended mobility. All these features must be assessed via technical homologation.

In addition to such technological and regulatory challenges, since the late 2000s, the automotive industry has been affected by a large number of drivers of change in the macroeconomic and social environments, which led to the relentless emergence of new lifestyle habits and customer needs. For instance, the emergence of fast-growing economies and new wealthy segments of society resulted in a growing demand for high-end goods and services, such as noise cancelling systems and self-repairing tires, which, in turn, have prompted more stringent regulations at both the national and international levels. The increasing number of vehicle models, with different tire fitments for each model, has led to a sudden increase in the number of single tire development projects. In the next few years, an even more dynamic scenario is envisaged for the automotive industry due to key drivers of change such as car electrification, car sharing and autonomous driving, with likely disruptive effects on tire characteristics and the overall business model of tire companies.

3.2. The rationale for TRM at Pirelli

The growing complexity and pace of change in the tire industry has resulted in the need for Pirelli to deeply revise its R&D efforts and overall innovation process to sustain the long-term performance of the company with regard to critical success factors, such as time to market, breadth of products and product features, and performance levels.

In early 2010, the top executives considered whether and how they could optimize their innovation projects (i.e., avoid redundancy) and more rapidly transfer new knowledge from the research centers to the product divisions. Overall, the rationale for a deep restructuring of R&D and innovation management in Pirelli was to identify, in a systematic way, emerging market opportunities and highlight the gaps in the overall project portfolio. Top executives felt that the challenge to respond to continuous changes in customer needs and market (regulatory) requirements was absorbing most of the R&D efforts at that time by diverting attention from long-term objectives and projects. The top executives also felt that the focus on current operations and short-term innovation projects prevented Pirelli from transferring the knowledge generated in a single organizational unit to another and from encoding the know-how developed in a single innovation project and transferring this know-how to the next project.

Faced with these challenges, in the early 2010s, senior R&D managers (especially the director of the R&D unit who reported directly to the CEO) considered TRM a promising tool for both expanding the time horizon of R&D projects and driving the transfer of new technological know-how among different units. Specifically, through TRM, the top executives aimed to increase the overall impact (and profitability) of R&D investments by enhancing the integration of the different expertise of technologists, design specialists, and marketing and product managers.

4. The design and implementation of a new approach to TRM at Pirelli

In 2010, an ad hoc research team (hereafter, TRM team) was established and charged with the design and implementation of the overall TRM framework of the company. This paper is based on the action research project carried out by this team, which included some R&D managers from Pirelli and academics. As the authors of this paper belong to the TRM team, they had privileged access to the data collected. Action research was adopted for the following two main reasons: the first reason is related to the need for an in-depth understanding of TRM and new product development in the context of a highly volatile business; the second reasons is related to the possible contribution to existing theory concerning innovation management (Greenwood and Levin, 1998; Ottosson, 2003).

The first task of the TRM team consisted of a systematic review of the TRM practices that had been carried out in other organizations and public institutions, as well as theoretical works in the field

(Carvalho et al., 2013; Petrick and Echols, 2004). This systematic review allowed the TRM team to identify several approaches to roadmapping, including those described by Caetano and Amard (2011), Daim and Oliver (2008), Gerdsri et al. (2009), Gershman et al. (2016), Holmes and Ferrill (2005), Jeong and Yoon (2015), Lee et al. (2007), Lee et al. (2008), and Lichtenthaler (2008). Contextually, the TRM team reviewed an existing database, i.e., the Project Portfolio Management (PPM hereafter) system, which tracked the R&D activities of Pirelli at that time with regard to the people involved and the expected time of completion. The team expanded the PPM and built a new database that tracked the likely impact of new technologies on product features and manufacturing processes with the aim to provide a more complete repository of the R&D and innovation knowledge available in the company. In 2011, the head of the R&D department reviewed and approved the final structure and contents of the new database, i.e., the Innovation Miner (iMiner hereafter). Then, the TRM team systematically interviewed all researchers and product managers in the company and collected information regarding their extant innovation projects in relation exactly to the entities of the iMiner, e.g., target product features, target performances, and tire components. Thus, the TRM team started populating the database, and the first prototype was released and made available to all R&D employees through the company intranet in 2015. A collaboration began with an external consulting firm specializing in innovation management. The initial prototype was subsequently refined, and in 2016, the final version currently used in Pirelli was released. Figure 1 illustrates the evolutionary process through which TRM was gradually introduced and embodied in the overall innovation process of Pirelli.

“Insert Figure 1 about here”

Today, the iMiner has become a key element in the ignition and implementation of TRM at Pirelli. Hereafter, in this section, we describe in detail each entity of this database and how it is concretely used to support TRM across the different business and organizational units of the company.

4.1. iMiner: Content and structure (database entities)

The iMiner database was conceived as a set of intertwined tables, each corresponding to a specific entity (i.e., field or dimension) that describes the innovation projects carried out by the company. Overall, the iMiner includes 9 tables/fields. These entities are as follows:

Product features. Product features encompass regulatory requirements and technical features such as “safe for people” (e.g., braking and handling in different conditions such as dry, wet, snowy, and iced roads); “extended mobility” (e.g., self-supporting or self-sealing tires); “safe for the planet/sustainability” (i.e., environmental sustainability, e.g., rolling resistance, external noise; social sustainability, e.g., internal noise; and economic sustainability, e.g., product cost, mileage); “aesthetics”; and “connectivity” (e.g., digitalization).

Product segments. Product segments encompass the different categories of vehicles using tires, namely, cars (e.g., SUVs—sport utility vehicles, UHPs—Ultra High Performance vehicles, city cars, electric vehicles); motorcycles (e.g., street, enduro) and bicycles.

Target performance features. Product targets are expressed in relation to each product feature (e.g., dry handling) as the percentage of improvement (e.g., 5%) expected or required compared with the current performance for the same feature.

Tire components. Tire components include bead filler, liner, nylon belt, tread, steel belt, plies, sidewall, and chafer.

Manufacturing stages. Manufacturing stages include the processing of raw materials, the mixing stage, the semifinishing stage, the building stage, the curing stage and the finishing stage.

Technology ideas. Technology ideas encompass all R&D initiatives and proposals aimed to innovate any products or product features. Technology ideas are categorized according to their main technological areas, i.e., materials, production process, tool design, tire design, testing methodologies, mathematical modeling, and electronics. Each technology idea is described in terms of chance of success, expected time of completion, and status.

Resources. This entity describes the resources required for the implementation of any technology idea, including the partners to involve (e.g., universities, private research centers, suppliers, and customers).

Technology projects. This entity describes the specific projects and people involved in the execution of technology ideas, their location (research centers), the time of completion and milestones, the objectives (product features affected), and the expected outcomes with regard to both tire components and the manufacturing processes.

Technology actions. This entity encompasses the specific activities designed for transferring the new knowledge generated by a technology idea into new products and product features.

Some key features of the iMiner are the clear distinction between the entity of 'technology idea' and the entity of 'technology projects' and the distinction between technology areas (materials, processes, modeling, and electronics) and product segments (within the car and moto businesses). The creation of the database involved the following two phases: the first phase addressed all technology ideas, and the second phase explored their likely impacts on product performance, product segments, tire components and manufacturing stages.

To facilitate a full understanding of the iMiner by any user within the company, the units of measure for each entity of the database were standardized. For instance, the time required for the development of a given technology was expressed in the number of years, and the target performance improvement of a given product feature was expressed as a percentage (incremental improvement) of the current performance level (i.e., the performance level at the time the R&D project started). Additionally, English was adopted as the language for the whole database.

4.2. iMiner and roadmaps

Due to its modular architecture, the iMiner allows the production of graphical representations, i.e., roadmaps, that describe the evolution over time of each entity of the database (e.g., a product feature or a product segment) and/or the linkages among different entities (e.g., technology ideas and product features; technology ideas and manufacturing processes; or technology ideas and technology projects). An ad hoc user interface enables the direct input of queries and the retrieval of any information available regarding the entities of the iMiner. This information is then collected through ad hoc reports that can be filed.

In particular, the iMiner allows R&D and product managers to create Pareto reports that highlight the most relevant product features in a given time horizon, i.e., the product features that underpin the highest number of future products and product segments. The outcomes of such Pareto analyses are roadmaps that illustrate, for each product feature, the target improvements and expected time of achievement.

5. iMiner, TRM, and innovation management at Pirelli: Some concrete examples

In 2010, when the top executives decided to use product and technology roadmaps, they were fully aware that it was not possible to develop a methodological approach that could make accurate forecasts about the long-term evolution of the turbulent tire and automotive industries. The iMiner was not intended to be a "crystal ball" through which R&D and innovation managers could anticipate the future but a tool facilitating the codification, sharing, and exploitation of new information regarding market and technological changes across different units and projects, ultimately enhancing the effectiveness of new product development in relation to such objectives as increasing the number of innovative product ideas, expediting the time to market, and exploiting technological synergies among different product platforms. The following examples are very helpful in providing empirical evidence regarding how the iMiner and TRM concretely contributed to these objectives. The first example is related to the development of product and technology roadmaps for the moto business unit. The second example relates to the improvement of cost efficiency across all business units. The third example relates to the formulation of the overall R&D and innovation plan of the company.

5.1. Product and technology roadmaps for the motorcycle business division

In June 2016, the chief operating officer (COO) of the motorcycle business unit decided to start a TRM project aiming to craft the overall innovation strategy of this division by identifying key technologies for future growth and contextually distinguishing the technologies that were already available (or under development) within the company from the technologies that had to be developed from scratch. This TRM project was labeled the “MOTO tires technology-product roadmap”. Figure 2 illustrates the main activities that were undertaken during this TRM project and the related outcomes.

“Insert Figure 2 about here”

As the first task, the TRM team, i.e., the same team that developed the iMiner, selected the R&D managers, market experts and product managers to be involved in the MOTO tires technology-product roadmap. The managers and experts belonged to different hierarchical levels, organizational units and R&D areas and were invited directly by the director of the R&D department and the head of the moto business unit. Then, the TRM exercise consisted of a series of workshops that involved 25 people.

A couple of weeks before the first workshop, the TRM team used the iMiner to select the most relevant product features for motorcycle tires in the next five years. Such a selection was based on a Pareto analysis that explored the product features addressed by all R&D projects carried out or planned within the company at that time; the most recurring product features belonged to the area of handling behavior (dry and wet). The iMiner contextually allowed the selection of the main innovation projects and technology areas underpinning the future development of these features. This documentation was sent to all participants before the first workshop so that they could share and individually evaluate such documentation as a common basis of data. Thus, the iMiner supported the systematic gathering of information in the typical initial idea discovery stage of a stage-gate innovation process.

Subsequently, during the workshop, this common basis of data facilitated the discussion and interaction among all managers and experts despite their different backgrounds. In particular, the iMiner had clearly highlighted four relevant product features in the area of handling behavior and mileage of tires. During the workshop, the participants were split into two different groups; each group, led by a marketing manager and a member of the TRM team, was asked to focus on two of these product features. Each group had to review the initial forecasts provided by the iMiner and provide its own forecasts about the coevolution of technologies, products, and performance improvements. The participants engaged in a brainstorming session through which they could share their insights and expectations. On the one hand, technologists and R&D experts benefited from the ideas of marketing managers, who shared their understanding of the most recent customer needs. On the other hand, the technologists and R&D managers transferred their understanding of the opportunities related to new R&D and technology projects to the marketing managers. For instance, a technologist drew the shape of longitudinal grooves on a whiteboard to explain the effects of these grooves on the selected product features and illustrate how new technological tools could help to test these effects. Thus, the brainstorming session facilitated the systematic analysis of information in the initial idea discovery stage of a typical stage-gate process.

Overall, the data originally provided by the iMiner were investigated, debated, and finally revised. At the end of the brainstorming sessions, each group summarized its findings on a whiteboard, and then, in the second part of the workshop, the two groups met and shared their findings. A matrix was eventually built in which key technologies were listed in the columns and key product and product features were listed in the rows. In the cells of the matrix, the participants indicated the year when a certain technology was expected to improve a certain performance feature of a certain product and the amount of the improvement. Thus, the second part of the workshop supported the elaboration of deliverables in the initial idea discovery stage of a typical stage-gate process.

Altogether, the workshop lasted two days. Soon after the workshop, the iMiner was updated by the TRM team, and the findings were embedded in the database. A follow-up meeting was scheduled with the aim to decide whether to invest in the project and draft an action plan for the development of the key technologies and products identified in the workshop. The follow-up meeting was led by the COO of the moto business unit and served as the decision gate of the initial ideas discovery stage of a typical stage-gate process.

A major outcome of the MOTO tires technology-product roadmap was the development of a new product, i.e., the P Zero Velos, the commercialization of which officially started in September 2017. This product targeted the bicycle market, which was untapped until that time by the company. TRM helped

Pirelli's managers seize the opportunity to enter this growing market by exploiting some of the technological and brand skills that the company had already developed in its existing businesses. The TRM workshop enabled the participants to identify the product features and technologies that could easily be transferred from the car and motorcycle product platforms, such as the innovative Pirelli SmartNET™ Silica, which improves the product features of rolling resistance and wet grip. SmartNET™ Silica is a patented technology that was developed in the mid-2010s for car and motorcycle tires. Remarkably, the P Zero Velos used the same logo as Pirelli's Formula One tires. In 2018, for the first time, a team of professional bikers used the new product at the Tour de France.

5.2. Product and technology roadmaps for cost efficiency

After the release of the iMiner, TRM has been systemically used to support not only the innovation plans of each business unit but also horizontal projects across units. This was the case, for instance, for a roadmap project that was carried out in late 2016 through early 2017 and specifically addressed the product feature of cost efficiency. This TRM project was implemented under the sponsorship of the director of the R&D department and the head of the Processes and Equipment Development organizational unit (Pirelli develops most of the equipment and machines for its manufacturing processes internally. Over time, these activities have been grouped in a stand-alone organizational division, namely, the Processes and Equipment Development division).

An initial workshop was scheduled in late 2016 involving R&D and product managers from the car and moto business units. The participants were divided into the following two groups: the first group focused on the key components and materials of tires ("product view"), and the second group focused on the main stages of the manufacturing processes ("factory view"). Both groups used the iMiner to obtain and share a common basis of knowledge about the main technologies affecting the cost performance of all product platforms and all factories of the company with regard to both fixed costs, e.g., capital expenditures, and variable costs, e.g., labor and raw materials (information gathering in the initial ideas discovery stage of a typical stage-gate process).

A brainstorming session then started, and each group explored the technologies that could affect the cost performance of Pirelli in the next five years, with the aim of assessing and expanding the initial list of technologies provided by the iMiner. While R&D and innovation managers had traditionally focused on their specific projects and activities, e.g., the development of a given technology for a specific tire model for motorcycles, the TRM project allowed the managers to reflect on the impact that such technology could have on the overall product portfolio and processes of the company (information analysis). The two groups met again in a plenary session and explored the likely synergies and opportunities for cost reduction (elaboration of deliverables). At the end of the meeting, the TRM team transferred the outcomes into the iMiner.

After the workshop, which lasted 2 days, a cross-functional team of experts in R&D, manufacturing, controlling, and purchasing was established. The team designed an action plan for developing the most relevant technologies identified in the TRM project and supporting their transfer across all the Pirelli factories (stop/go decision gate). As a result, the Board of Directors expects to create efficiencies equal to 1.0% of revenues between 2017 and 2020.

5.3. TRM and the formulation of the Pirelli general innovation plan

The iMiner and TRM had a deep impact not only on specific innovation projects but also on the overall innovation strategy of Pirelli. The action plans designed at the end of each TRM project are shared with the top executives of the company, particularly the director of the R&D department and the heads of the business units. Afterwards, these action plans are merged into a broad, unified ("general") action plan that depicts synergies and priorities in technologies, products, and people/resources. Such a general action plan typically covers a time horizon of up to five years.

Remarkably, the innovation strategies of leading tire companies have been traditionally built around the improvement of historical performance features; this was also the case for Pirelli. However, the iMiner and TRM strongly contributed to changing how performance targets for the car and moto business units are established, by pushing R&D and innovation managers—including the heads of the business units—to extend the planning horizon and adopt a proactive approach. Rather than looking simply at the historical trajectories of improvements in product and performance features, Pirelli's R&D and innovation managers now systematically search and prepare for possible disruptions, e.g., the advent of self-driving or electric cars. In particular, the long-term partnership with Formula One racing teams provides an opportunity to test and develop state-of-the-art solutions that the iMiner and TRM contribute to transferring to product platforms across the whole company.

The general innovation plan currently represents a key component of the broader strategy formulation and planning process of Pirelli. Recently, in relation to the IPO (initial public offering) of the company in October 2017 (which followed the acquisition of Pirelli by ChemChina in 2015 and its delisting in the same year), the general innovation plan helped to define the market value of Pirelli. The general innovation plan also contributed to establishing the strategic objective of increasing the average annual revenues of the company by 9% in the 2018-2020 three-year term.

6. A framework for TRM and innovation management

The previous examples show how the iMiner and TRM contributed to new product development in Pirelli in relation to the systematic gathering, analysis, elaboration, and sharing of information regarding new technologies and markets across the different functions and business units of the company. Overall, our research findings emphasize the key role of the iMiner as the core component of an innovative approach to TRM and suggest an emerging conceptual framework for the relationship between TRM and the overall innovation process of a corporate organization.

6.1 TRM and innovation management: The role of the iMiner

The iMiner enables Pirelli's managers to easily begin and implement ad hoc TRM projects that address any entity in the database, from product features to technology ideas and from product segments to manufacturing processes. A typical TRM project consists of a series of formal workshops and meetings that are scheduled in a flexible way and involve researchers, technologists, marketing managers, strategic planners and product specialists from different business units and geographic locations. The iMiner provides an initial, shared basis of information that creates a common language and facilitates strategic dialogue among the different participants in TRM. Most TRM projects carried out by Pirelli thus far have been designed based on either product features (e.g., rolling resistance) or product families/markets (e.g., tires for motorbikes).

In the first case, through a basic query (Pareto analysis), R&D managers can determine the product features that are addressed by most technology ideas and projects in the iMiner itself and the product features for which the most substantial performance improvements are required. Ad hoc workshops are then held to explore the future evolution of the main technologies underpinning these product features. Typically, these product feature-oriented TRM projects are promoted and supported by the director of the R&D unit.

In the second case, the product managers of each business unit (car, moto) can use the iMiner to obtain Pareto analyses that provide a clear, overall picture of the new products under development within the company and the main technologies related to these products. Ad hoc workshops are then held to address the future evolution of—especially the mutual influences between—products and technologies. Typically, these market/product family-oriented TRM projects have been promoted by the directors of the business units.

At the end of any TRM project, a stop/go decision is made, and eventually, an action plan is designed with regard to the concrete development of the technologies considered in the TRM project, their transfer into new product and product features, and the commercialization of these products. Such resulting roadmaps represent the official output of each TRM project and contribute to the progressive update of the iMiner.

6.2. iMiner, TRM, and innovation management

Since the release of the first prototype in 2015, the iMiner has gradually become a pillar of knowledge management at Pirelli. Regardless of their location, Pirelli's managers can easily access and use this database as a repository for the information that the company has accumulated throughout its history and from its past experience. The iMiner is a "living' document" that is continuously updated and improved as the result of the TRM activities that the iMiner is meant to support.

In a few years, the integrated use of the iMiner and TRM—or, more precisely, the innovative approach to TRM that has been built around the iMiner—has allowed Pirelli to enhance the effectiveness of its innovation process by helping managers across the company codify, share, and elaborate their knowledge regarding new technologies, products, and markets. As new information becomes available in a given innovation project, this information is embedded in the iMiner and made available to the next TRM workshops and innovation project. This knowledge management process involves and enhances all activities recommended by Cooper (2008) for the idea generation stage of a typical stage-gate model, i.e., the gathering of information to reduce key uncertainties and risks, the analysis of information, and the elaboration of deliverables in preparation for the go/kill decision. Table 1 illustrates the differences introduced by the iMiner and TRM at Pirelli in relation to the execution of these activities by comparing the innovation process of the company before and after the iMiner and TRM.

"Insert Table 1 about here"

The resulting benefits were significant and included an increased number of new product concepts, acceleration of the time to market, and exploitation of technological synergies among different product platforms.

6.3. Managerial implications and future developments

After the full release of the iMiner in 2015, the use of this database and TRM has become popular within the R&D department and all the business units in the company. Several TRM projects have been already completed, often under the sponsorship and through the direct involvement of the director of the R&D

department and the heads of the business units. The action plans that resulted from these TRM projects have concretely contributed to shaping the strategic agenda and innovation efforts of Pirelli (e.g., through the launch of new products, such as the P Zero Velos) and the embedding of their findings in the general innovation plan of the company. The growing access to the iMiner—throughout all research centers of the firm—and the growing number of TRM projects all highlight the profitable and consistent use of this database and TRM in real-life conditions and, thereby, to the overall effectiveness of the action research project that was behind them (Coughlan and Coghlan, 2002).

However, despite the considerable positive feedback received so far by users across the many geographic bases and organizational units of Pirelli and the full endorsement of senior R&D managers and top executives, some relevant limitations have emerged in relation to the current structure and functionalities of the iMiner. The gradual awareness of such limitations laid the foundations for the current and future development of the iMiner and TRM.

First, the collection of data covering the numerous entities of the iMiner is burdensome and time consuming, involving not only the TRM team but also several managers and employees. In some cases, it was difficult to formalize the knowledge of these managers and embed it in the iMiner because some of them were reluctant to put time and effort into the iMiner. This reluctance, however, was gradually overcome due to the support of the top executives (especially the R&D director and the heads of the business units). Additionally, as they became increasingly familiar with the database and TRM workshops, the managers and employees refined their capability to gather and analyze information from the database over time and eventually add new information to the database.

Second, whereas the widespread opportunity to access and add data to the iMiner has proven to be a valuable feature, some users have pointed to the need to identify someone who is ultimately responsible for guaranteeing the reliability of the contents of the database. Although the iMiner can track the changes to and evolution of its contents, the continuous and widespread revision has created some confusion and criticism regarding the consistency of the data, which is particularly the case for those marketing managers and technologists who sometimes have opinions that radically differ from the information (e.g., forecasts about the commercial viability of a new technology) that they find in the iMiner. Such differences have also emerged in the TRM workshops and clearly emphasize the need for a partial rethinking of the process through which the opinions of experts are collected. In particular, the TRM team is currently evaluating whether the adoption of methods, such as Delphi, might help increase the reliability of the data in the iMiner.

The third issue is related to the involvement of experts outside Pirelli. On the one hand, in the last decade, the company has developed a wide network of partnerships with external research centers and universities according to the open innovation paradigm (Ahn et al., 2015; Lichtenthaler, 2010). The iMiner itself is meant to enhance TRM and absorptive capacity in an open innovation environment (Caetano and Amaral, 2011; Spithoven et al., 2011). On the other hand, thus far, the iMiner and TRM projects have basically involved, at least directly, only company employees. In the long term, given the growing complexity and dynamism of the automotive and tire industries, such limitations might seriously undermine the completeness and reliability of the database and thereby of TRM. The involvement of experts from outside the company should be designed with the twofold objective of preventing the spillover of sensitive information while allowing the management of an increased amount of data. Therefore, some senior executives have also noted the opportunity to develop a systematic technology scanning system that monitors and embeds into the iMiner, in real time, new information regarding emerging technologies as soon as this information becomes available on the Internet or other public sources (as typical of computer-based roadmapping approaches).

Fourth, the integration of individual product and technology roadmaps into the general innovation plan that summarizes the future innovation strategy of the company basically relies on the personal skills and opinions of the top executives. By the end of 2019, there is no function or query in the iMiner that might assist executives in this task through a formal, systematic, and quantitative method.

Finally, future developments of the iMiner might involve more sophisticated approaches to network analysis that are able to visualize the mutual influences of technologies with regard to their joint impact on the performance of similar products. This change would simplify the comparison of business projects that are “technologically” distant but address similar market and product objectives. Another opportunity for the future development of the iMiner, which is currently under consideration by the TRM team, relates to the addition of a specific function that depicts different scenarios, i.e., alternative patterns of evolution for a given technology or market.

7. Discussion

In the early 2010s, the challenge posed by the increased turbulence of the automotive and tires industries pushed Pirelli to profoundly restructure its R&D and innovation process. The industry turbulence stemmed from the fast pace of change in regulations and customer needs and resulted in considerable growth in the number of product platforms, products and performance features.

This paper describes the innovative approach to TRM designed and implemented by Pirelli to increase its responsiveness to its dynamic environment. The innovative framework for TRM was the result of an action research project that started in 2010. Its effectiveness was tested both externally through a comparison with TRM practices in other organizations and an analysis of its theoretical contribution and internally through an analysis of its benefits as perceived by the R&D and innovation managers that applied it (Birkinshaw et al., 2008).

First, a systematic literature review was carried out to identify the practices adopted in the business and public sectors since the early 2000s in addition to theoretical works in the field. Although the previous work of scholars covered a large number of application domains, such as TRM for SMEs, research centers, partnerships and open innovation, we found a gap regarding the design and implementation of new, flexible TRM methods for large corporate organizations. Lee et al. (2012) and Simonse et al. (2015) also highlighted this gap in the extant literature.

In particular, despite theoretical papers praising the role of TRM in innovation management (e.g., Kostoff and Schaller, 2001), we have found little empirical evidence regarding how large corporate firms and multinational companies have evolved their approaches to TRM over the last decade so that they could improve their overall innovation processes and adapt to a world of rapid change. By describing our action research project with Pirelli, we contribute to filling this gap.

The core novelty of the proposed approach to TRM is the iMiner database, which currently serves as a flexible and easily accessible repository for the collective knowledge of Pirelli. The iMiner and TRM set the ground for enhancing new product development (e.g., sharing of information across different projects, increased number of new product concepts, accelerated time to market, and exploitation of technological synergies among different product platforms) in particular relation to the effectiveness of the initial idea generation stage of a typical stage-gate innovation process. Precisely, the iMiner and TRM support the methodical design and implementation of all key recommended activities of information gathering, information analysis, and elaboration of deliverables (Cooper, 2008). The iMiner supports all the TRM exercises of the company that, in turn, provide an opportunity to update the iMiner by means of a continuous, yet not rigid, process. The iMiner provides a systematic and shared framework for TRM with clear goals and activities while offering considerable freedom for the start-up and implementation of ad hoc TRM exercises.

The empirical findings from Pirelli suggest that TRM can be seamlessly integrated into the overall innovation process of corporate organizations by increasing its effectiveness and efficiency (Tidd and Thuriaux-Aleman, 2006). The novel tool (iMiner) and approach to TRM developed by Pirelli is likely to be beneficial for the innovation efforts of a wide array of firms, especially in industries in which technology and regulation are the main drivers of change and new customer needs and product features relentlessly come to the fore. For instance, this is the case in ICT sectors, such as mobile communication, consumer electronics, multimedia services, and digital health, in which incumbent players (such as Philips) have already used product and technology roadmaps (Groenveld, 1997), or the automotive industry in which leading firms, such as Daimler and Audi, have traditionally applied anticipatory approaches to strategic decision making (Ruff, 2015). More generally, the innovative approach to TRM described in this paper might be helpful for companies that increasingly struggle to exploit the outcomes (e.g., new information and data) of their R&D projects with regard to the transfer of such outcomes among different teams and organizational units.

8. Conclusion

Overall, this paper aims to expand our understanding of TRM and its role in new product development. We focused on the exemplar case of a leading firm that used roadmapping to cope with the growing turbulence of its business environment. Our research setting, data collection and data analysis were designed to enhance the construct and internal validity of our conceptual framework.

However, it is critical to note that our work is based on a single case. We hope that future research efforts might further test the advantages and disadvantages of the innovative approach to TRM we present in this paper by applying it to different companies and industries. This might be the case, for instance, for global and technology-intensive businesses such as electronics and communication, in which R&D and innovation managers are facing similar challenges of increased volatility and complexity due to the high number of drivers of change in technology, regulations, and customer needs. Furthermore, while the iMiner and TRM are basically used in Pirelli during the initial idea generation stage of the typical stage-gate process, future research efforts might explore the use of similar tools and roadmapping approaches in the case of the following stages from idea scoping to post-launch review.

We particularly hope that scholars and practitioners might build upon our work to further enhance the embedding of roadmaps into the overall innovation process of a firm and the impact of TRM on new product development. Pirelli itself, given its ongoing efforts to cope with the limitations of its own approach to TRM, might represent a compelling case for future research.

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	Before the iMiner and TRM	After the iMiner and TRM (main benefits)
Information gathering activities	Informal, unstructured process	Formal, methodic process that improves the collection of and access to the existing pool of knowledge available within the whole company When a new TRM project begins, the TRM team works together with the director of the R&D unit and/or the directors of the business units to select the R&D managers, product managers, marketing and technology experts, and other company employees (and, in some cases, external experts) that should participate in the TRM project. Then, these managers are given an initial roadmap that summarizes the relevant information already available in the iMiner regarding the likely coevolution of technologies, products, and product features/performances. This information represents the codification of the previous experience (e.g., innovation projects and R&D activities) of the company across its different units and functions. This initial roadmap is shared as a common set of data by all participants in the TRM project, who then absorb and further elaborate on the data based on their own personal insights and expertise. The iMiner usually challenges the established opinions of managers, most often when the data are borrowed from other (previous) R&D projects in which these managers were not involved. Thus, when a TRM project begins, the iMiner acts as a data source that is easily and directly accessible to each manager or expert participating in the initial idea generation stage of a typical stage-gate process.
Information analysis	Unstructured process with limited dialogue and transfer of know-how among different business units and different R&D and innovation projects	Continuous, systematic process that expands the initial set of data available in the company and improves the understanding of these data After the start of a TRM project, workshops and meetings lead the participants to share their perceptions regarding the accuracy and thoroughness of the initial roadmaps/forecasts provided by the iMiner. Managers usually raise concerns regarding the anticipated impact of a given technology and customers' acceptance of/demand for new technologies and product features. The direct interaction among managers with different backgrounds (e.g., R&D, marketing, and operations) tends to foster provocative thinking; managers attempt to sustain their arguments by sharing their own

		experiences, insights and expectations about technologies and customer needs, even when these experiences and insights are difficult to formalize through quantitative data. Thus, the TRM workshops enable the participants to systematically analyze their insights and information about changes in the tire and automotive industries (information analysis in the idea generation stage of a typical stage-gate process).
Elaboration of deliverables	Unstructured process with limited dialogue and integration of expertise among technologists, design specialists, marketing and product managers in different business units	Methodic process that makes managers' assumptions about future markets explicit (and sets the ground for the following TRM exercises) After sharing their expectations and personal opinions in the TRM workshops, the participants are required to translate these opinions into a new and consistent set of forecasts by reaching a consensus regarding the likely coevolution of new technologies, products, and markets. Thus, managers elaborate upon the findings of the TRM workshops in formal deliverables that are then used to decide whether to invest in the development of a new product idea (elaboration of deliverables in the idea generation stage of a typical stage-gate process). The deliverables are also used to update the data (entities) in the iMiner. These updates are typically carried out by the TRM team as at least one member attends each TRM workshop. Precisely, once updated, after the conclusion of a TRM project, the information and content of the iMiner are shared throughout the organization and made available to R&D and product managers who were not directly involved in the TRM workshops. Thus, these managers can revise and further elaborate the iMiner by expanding the information stored in the database and making it available to the next TRM project.

Table 1. Impact of the iMiner and TRM on the innovation process in Pirelli in relation to the recommended activities of the idea generation stage of a typical stage-gate process

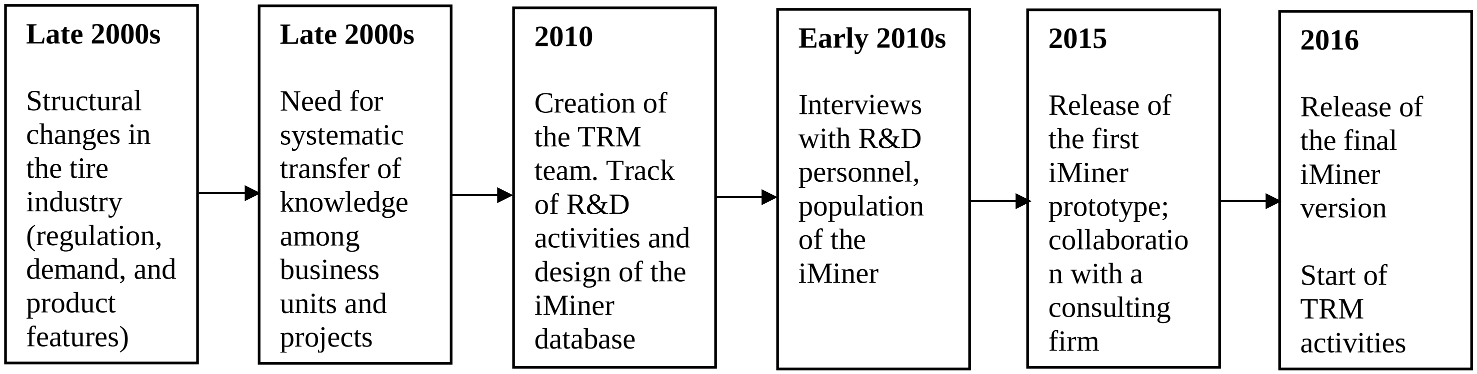

Figure 1. The evolutionary process of technology roadmapping at Pirelli

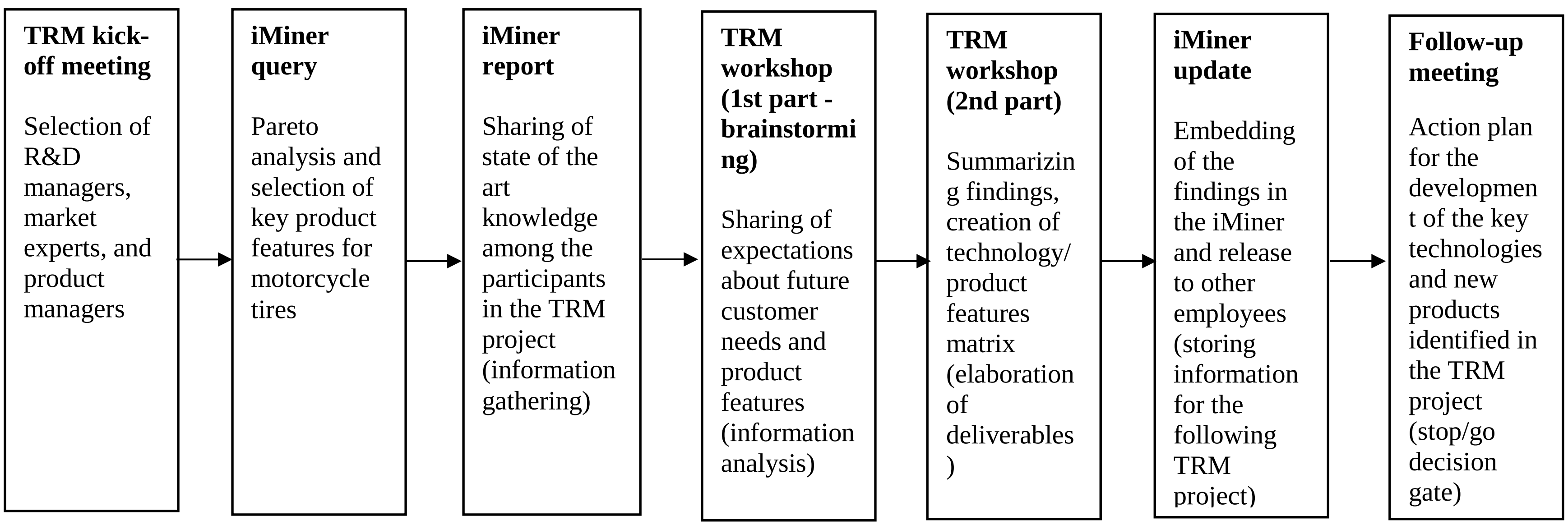

Figure 2. The TRM project for the motorcycle business unit of Pirelli