Development process of technological process innovation in the manufacturing industry

A mixed methods study

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Date: August 20, 2019

Acknowledgements

Throughout the writing of this thesis I received the support of many. I would like to offer my special thanks to my supervisor, dr. P.E.M. Ligthart, for giving advice and guidance during the entire process of writing, whereby he supported me via suggestions and his enthusiasm. In addition, I would like to thank the respondents for their cooperation and their hospitality to receive me at their company, whereby the conversations led to interesting findings and insights. Finally, I would like to thank my dear family and friends for encouraging me and giving me priceless advice.

After two years at the Radboud University, where I followed the pre-master Business Administration and the master Strategic Management, my career as a student has come to an end. I hereby present my final piece of work as a master student Strategic Management.

Marijn Bouvy

Nijmegen, August 20, 2019

Abstract

Companies must innovate to remain competitive in an increasingly changing environment. They can innovate their processes, whereby the implementation of technologies in the production process leads to technological process innovation (hereinafter referred to as process innovations). Compared to product innovation, little research has been done regarding the development and implementation of process innovations. In addition, many success stories of open innovation can be found in the literature, however, open innovation focusing on process innovation remains relatively neglected. This has led this study to focus on how process innovation is developed and which innovation approach -open versus closed- is most effective for this, whereby the innovation approaches distinguishes themselves in the way in which internal and external R&D are utilized. This study focuses on SMEs in the manufacturing industry. In this study it was theorized that internal R&D and open innovation have a positive influence on the realization of process innovation, due to the use of tacit knowledge of regular employees and the use of external expertise. To obtain results, a mixed method study has been applied. First, use has been made from the European Manufacturing Survey (2015). A multiple regression analysis examined the effect of internal R&D on process innovation and the moderating effect of external R&D on this relationship. It turns out that these relationships were not significant and therefore could not be confirmed. Second, semi-structured interviews were conducted to investigate these relationships and to get more insight into the development process of process innovation. One finding based on the qualitative analysis in this study was that open innovation is the key in innovating processes by SMEs. Another finding based on the qualitative analysis is that a modified version of the Stage-Gate model of Cooper is applicable to the development process of process innovation, wherein other activities play a role in comparison to product innovation. The results of this study have theoretical implications but are also useful for SMEs that want to realize process innovations. It describes ways how SMEs can realize process innovations in an effective way. The findings together with the recommendations for future research will help to understand and extend the existing literature on the development process of process innovation and the role of open innovation in it.

Keywords: external R&D, internal R&D, manufacturing industry, open innovation, SME, technological process innovation

Table of contents

1. Introduction

Companies must innovate to remain competitive in an increasingly changing environment (Crossan & Apaydin, 2010). Companies can innovate products or processes, and these are interlinked as product innovation leads to process innovation (Kraft, 1990) (referring to a renewal of production processes and technologies). Implementing these technologies in production processes results in Technological Process Innovation (hereinafter referred to as process innovation). Currently scholars mostly describe innovation as an outcome (Crossan & Apaydin, 2010) instead of innovation as a process, the latter therefore remains understudied (Frishammar, Kurkkio, Abrahamsson & Lichtenthaler., 2012; Lager, 2010; Piening & Salge, 2015). Although it is important to consider product and process innovations separately, in the literature concerning the development and implementation of process innovations there is no distinction made (Tidd, Bessant & Pavitt, 2005). Furthermore, it is still a challenge for companies to acquire knowledge to innovate their processes. Some companies rely for their R&D entirely on closed innovation, whereas others have fully open approaches to innovation (Hung & Chou, 2013) and work closely together with external parties (Van de Vrande, De Jong, Vanhaverbeke & De Rochemont., 2009). The effectiveness of these innovation approaches -open versus closed- to innovate processes is however challenged (West & Gallagher, 2006) and therefore of interest to be studied in more detail. The focus of this thesis is how process innovation is developed and which innovation approach is most effective for this.

1.1 Problem statement

Innovation can be distinguished in two types: product innovation and process innovation (OECD, 2018; Utterback & Abernathy, 1975; Damanpour & Aravind, 2006). Product innovation refers to a new end product or a new service itself (OECD, 2018). While process innovation refers to an innovation in the production process or the delivery process of products or services (Damanpour & Gopalakrishnan, 2001). Another difference is that product innovation is aimed at external customers, while process innovations focuses on activities within the company such as logistics and production. In addition, they differ from each other in the following aspects, such as the objective to innovate, competitive impact, rareness, imitability and substitutability (Un & Asakawa, 2015). Hence, it cannot always be assumed that the insights gained through research focused on product innovations also apply to process innovation. (Damanpour, 2010; Pisano & Shih, 2012).

Each type of innovation can have its own development process by which an innovative idea is developed towards an actual final outcome being the innovation. As indicated earlier, this thesis focusses on process innovation. Compared to product innovation, little research has been done regarding the development and implementation of process innovations (Frishammar et al., 2012; Lager, 2010). According to Frishammar et al. (2012), process developments, similarly to product developments, are made possible through "*planned, structured and formalized work processes*" (p. 526). Although it is important to separate product from process innovations (Tidd et al., 2005), this is not done in the literature concerning the development and implementation of process innovations. As a result, the same principles are applied to both types of innovation (e.g., Utterback, 1971). Nonetheless, the existing literature recognizes various stages in the development and implementation of process innovations. In these various stages relevant activities take place and the necessary objectives are formulated (e.g., Kurkkio, Frishammer & Lichtenthaler, 2011; Voss , 1992). These stages are also recognized by Hollen, Van Den Bosch and Volberda (2013), whereby the development of process innovation is cut into several pieces. Ultimately, all of these phases can be found in the Stage-Gate model from Cooper (2008).

The development of a process innovation, thus the steps and procedures that are taken prior to the outcome of process innovation can either be realized through an open or closed approach in which a company either works together with other parties or innovates on their own (e.g. Chesbrough, 2003; Hung & Chou, 2013). Both in closed innovation and in open innovation, internal R&D is of great importance when the value of new ideas must be assessed and applied in the company's own products and processes. With open innovation, external R&D complements internal R&D (Chesbrough, 2003).

Many success stories of open innovation can be found in the literature but focus mainly on product innovation (Huizingh, 2011). Open innovation focusing on process innovation remains relatively neglected (Huizingh, 2011; Un & Asakawa, 2015; West & Gallagher, 2006). Therefore, it is important to investigate whether open innovation has an influence on process innovation. Although this phenomenon appears throughout many industries, the focus of this thesis is manufacturing industry. This industry is facing new challenges regarding digitalization of their production processes (Baur and Wee, 2015) to maintain competitiveness. Companies must prepare for changes that this new way of producing entails (Baur and Wee, 2015).

1.2 Objectives, Research Question & Relevance

The main objective of this thesis is to study how an open innovation approach affects process innovation, and the particular role of internal and external R&D activities. This thesis describes the degree of internal R&D and open innovation activities, that in turn determine the extent to which a company is capable to independently develop its own process innovations. The process innovations intensity indicates to what extent a company incorporates new technologies into their processes.

The realization of process innovations depends on a development process, influenced by open innovation. Companies that gain insight in the development of process innovations are likely to be more capable to identify any problems at an early stage when designing new process innovations.

The following research question is formulated, with regard to the research objective:

What is the influence of internal R&D and open innovation on the technological process innovation and its development process in the manufacturing industry?

To answer this research question both a quantitative and an qualitative research method is applied. This mixed approach is important to be able to look at how many (time and human) resources are invested in R&D activities to realize process innovations, this is done by quantitative analysis. But also to be able to look a level deeper to see which particular activities really matter for process innovation and what the interaction is between internal and external R&D capabilities, this is done by qualitative analysis.

This thesis contributes to the literature because it is among the first to focus on analysing the development of process innovations. The literature has primarily focused on the development process of product innovation. This thesis argues that companies can benefit from R&D partnerships when they develop process innovations, even though process innovations are primarily internal and tacit. In addition, this thesis shows the sequence of activities (steps) that play an important role in the development of process innovations, helping managers to better understand and manage the development of process innovations.

The practical contribution lies in that Dutch manufacturing companies are still at the beginning in the application of advanced new technologies in their production processes (Van Helmond, Kok, Ligthart & Vaessen, 2018). However, many companies themselves do not have the knowledge about how to implement technology in their processes. This study explains how these companies still can innovate effectively by using an open innovation approach.

1.3 Outline of the master thesis

In the next chapter the relevant literature is discussed, starting with the meaning of process innovations. Then two innovation approaches -open versus closed- are described. Moreover, the role of internal and external R&D in the two approaches are described. The third chapter describes the different relationships between the concepts from which hypotheses arise and leads to a conceptual model. The fourth chapter describes theory that is used for the development process of process innovation, including the development process of process innovations through the lens of the Stage-Gate model and learning strategies. The fifth chapter describes that a mixed method is used in this study. A quantitative analysis was used to investigate the hypotheses and a qualitative analysis was used to gain more understanding of the concepts and their relationships. Chapter six first present the results of the quantitative analysis based on data from the European Manufacturing Survey (2015). Subsequently, the results of the qualitative analysis are presented, which are based on data from the six semi-structured interviews conducted. The final chapter provides conclusions. Furthermore, the limitations of the study are indicated and recommendations for further research are presented.

2. Theoretical framework

The purpose of this chapter is to gain more insight into the concepts that play a role in the stated research question. In addition, it will become clear how this thesis will look at the sequence of activities that may be important for the development of process innovations.

2.1 Defining technological process innovations

The OECD (2005, p. 32) defines process innovations as: "*the adoption of technologically new or significantly improved production methods, including methods of product delivery. These methods may involve changes in equipment, or production organisation, or a combination of these changes, and may be derived from the use of new knowledge. The methods may be intended to produce or deliver technologically new or improved products, which cannot be produced or delivered using conventional production methods, or essentially to increase the production or delivery efficiency of existing products*". This is in line with Garcia and Calantone (2002), who argue that the primary focus of process innovations is on improving the efficiency of the production process.

Furthermore, when process innovations are discussed, it often refers to the installation of equipment and new machines with the aim of improving technological performance. Technological performance means: the improvement of the production and delivery methods of the company. In this study the definition of the OECD is used, where the emphasis is on improving production line.

Some scholars argue that it is necessary make a clear distinction between technological process innovations and organizational process innovations (Edquist, Hommen & McKelvey, 2001), whereby a distinction is made between process innovations that are "*technology-related*" and innovations that involve "*no technological elements*" and therefore only focus on human resource coordination. However, in practice it appears to be difficult to separate technological process innovations from organizational process innovations because process innovations often cause technological and organizational changes (Reichstein & Salter, 2006). Although this distinction is difficult to maintain, in this thesis the focus will be on technological process innovations, because technological process innovations are most relevant due to the type of industry for this thesis (manufacturing industry).

2.2 Innovation approaches

The development of a company's process innovation depends on how a company gains access to knowledge for innovation, and this is dependent on a company's market position. Four strategies can be distinguished in the innovation activities that a company carries out (Miles, Snow, Meyer & Coleman, 1978). Firstly, a company with a *defending* strategy will look at how to innovate to improve production, while the second, a *prospector* will innovate to serve a new market. The final two, companies with a *reactive* or *analysing* strategy will be more reserved in their innovations (Miles et al., 1978). The study by Miles et al. (1978) shows that each strategy innovates from a different purpose, which in turn determines to what extent innovation takes place. Un and Rodriquez (2018) demonstrate in their study that a balance between internal and external R&D, also referred to as an open innovation approach, is most effective. Before the concept of open innovation will be discussed, the concept of closed innovation must first be explained.

Closed innovation

In closed innovation, ideas are generated, developed and commercialized within the firm boundaries (Chesbrough, 2003). This approach requires R&D activities with an emphasis on self-reliance, which allows the organization to have full control over the innovation process (Chesbrough, 2003). Closed innovation depends on R&D activities that take place entirely within the boundaries of the company. Hence, internal R&D can be described as a situation in which all R&D activities of a factory at the plant site are carried out by own R&D personnel (e.g. Love & Roper, 2002).

If an activity is an R&D activity, it should meet five core criteria: "*the activity must be: novel, creative, uncertain, systematic and transferable and/or reproducible*" (OECD, 2015, p. 28). R&D activities provide new knowledge that can result in process innovations. In this thesis, internal R&D relates to self-generating new knowledge that is needed to realize innovations.

Open innovation

For innovation to be open companies make also use of external R&D. External R&D can be defined as "*a situation in which all of a plant's R&D activities were carried out either by arm's length contractual agreement or by collaborative agreement which involved no direct use of R&D staff at the plant in question*" (Love & Roper, 2002, p. 13). The literature shows that the use of knowledge that is available outside the company offers advantages in the development of innovations (e.g. Huizingh, 2011). Utilizing knowledge from external R&D in combination with internal R&D leads to open innovation and can be described as "*commercializing external (as well as internal) ideas by deploying outside (as well as in-house) pathways to market*" (Chesbrough, 2003, p. 36). Furthermore, Lichtenthaler (2008, p. 148) describes open innovation as "*systematically relying on a firms dynamic capabilities of internally and externally carrying out the major technology* *management tasks, i.e., technology acquisition and technology exploitation, along the innovation process"*. Both Lichtenthaler and other scholars identify that open innovation has two important dimensions: External Technology Acquisition (ETA) and External Technology Exploitation (ETE) (Chesbrough, 2003; Chesbrough & Crowther, 2006; Lichtenthaler, 2008; Van de Vrande et al., 2009). ETA is also known as the outside-in process (Enkel, Gassmann & Chesbrough, 2009). ETA relates to the extent to which a company has access to available external technologies to complement its current technologies (Hung & Chou, 2013). With ETA, contacts outside the company play a major role, whereby external R&D is used in addition to internal R&D. Furthermore, ETE is also known as the inside-out process (Enkel, Gassmann & Chesbrough, 2009). With ETE, use is made of internal R&D and knowledge that is available within the company. Hence, ETE relates to the actions of a company with the aim of commercialization or the transfer of its technological knowledge to external parties in order to obtain financial or strategic benefits (Chesbrough & Crowther, 2006; Lichtenthaler, 2009). With open innovation, the technological knowledge that is exchanged between two parties is considered to be an economic good (Chesbrough, 2003; Lichtenthaler & Ernst, 2009). ETE enables a company, among other things, to direct projects to the external environment to utilize its technological knowledge or by making ideas available to the external environment by selling IP.

In addition to the outside-in and inside-out process, there is also a coupled process (ETA combined with ETE) (Enkel et al., 2009). In the coupled process, the outside-in process is combined with the inside-out process, which refers to complementary partners who engage in co-creation projects through alliances, cooperation and joint ventures. This process makes it possible for companies to gain new knowledge and resources that they do not have themselves.

In this thesis, the concept of open innovation will be used to examine which impact open innovation has on process innovation. ETA concerns the following practices: customer involvement, external networking, external participation, outsourcing R&D, inward licensing of intellectual property (Van de Vrande et al., 2009). ETE concerns the practices: venturing, outward licensing of intellectual property and involvement of non-R&D workers (Van de Vrande et al., 2009). The definitions of these practices can be found in Appendix I.

According to Van de Vrande et al. (2009) an open innovation model only arises when companies work closely together. It is necessary for both companies to acquire knowledge from each other (Van de Vrande et al., 2009). In this thesis open innovation is seen as a combination of internal R&D and external R&D (e.g., Chesbrough, 2003). With this definition, both ETA and ETE activities are considered (Van de Vrande et al., 2009) in which close cooperation between companies plays an important role.

2.3 Capabilities to innovate

Companies that are able to search and can integrate external knowledge with their internal knowledge will have more innovative capabilities and can achieve competitive advantage (Cantwell & Mudambi, 2005; as cited in Un & Rodríguez, 2018). This is in line with the knowledge-based view (e.g., Kogut and Zander, 1992; Nonaka, 1994). According to the knowledge-based view, knowledge can be seen as strategic asset that explains the existence of firms and why some firms are more successful than others. (Un & Rodríguez, 2018). Firms are seen as mechanisms that are capable of creating, integrating and transferring knowledge. Moreover, knowledge as an asset can be seen as a source of sustainable competitive advantage (Barney, 1991). First, knowledge is valuable because it enables a company to meet the needs of customers. Second, knowledge can be considered rare because it varies among individuals and companies. Third, it appears that knowledge is difficult to imitate because individuals also have tacit knowledge. Fourth, knowledge is difficult to substitute because it is rarely clear how a company obtains knowledge and what logic is behind it (Un & Rodríguez, 2018). Hence, a company's own knowledge base plays a key role in the steps and procedures preceding process innovation.

2.4 R&D in the manufacturing industry

In the development process of process innovations R&D is of importance, because R&D is an instrument for acquiring new knowledge. Since the intensity of R&D varies per sector, it is important to asses in which sectors R&D intensity is highest (The Hague Centre for Strategic Studies & TNO, 2013). Economists express R&D intensity in the percentage of the Gross Domestic Product (GDP). This thesis focusses on the manufacturing industry in the Netherlands. According to Muizer (2013, p. 7) "*The manufacturing industry includes companies that process materials into new products.*". In this thesis, the term manufacturing Industry is understood to be the sector that deals with the production of discrete parts.

In 2010, companies in the Netherlands invested a total of 5.2 billion Euros in R&D. (The Hague Centre for Strategic Studies & TNO, 2013). According to The Hague Centre for Strategic Studies and TNO (2013) the R&D intensity of the sectors electronic industry and machinery industry are particularly high. Since the electronic industry and machine industry can be classified under the Manufacturing Industry, which respect to this thesis, the Manufacturing Industry is an interesting group to investigate.

2.5 Summary

In this chapter the characteristics of process innovation and two innovation approaches -open versus closed- were discussed. These approaches distinguish themselves in the role of internal and external R&D. Furthermore, process innovation is the result of the transformation of the current production process into an improved production process. This transformation implies the introduction of new knowledge into the production process. Process innovations can be the result of open innovation, which in turn can be distinguished in ETE and ETA. With ETE, a company's own knowledge pool is exploited. With ETA new knowledge is acquired from external parties. ETE and ETA relate to the extent to which external R&D is used compared to internal R&D. The knowledge that comes from this R&D is useful in the development of process innovations.

3 Hypothesis development: the relation between open innovation and process innovation

This chapter looks in more detail at the hypotheses that have been drawn up on the basis of literature. Figure 3.1 sets up the conceptual model under the hypotheses.

3.1 The effect of open innovation on process innovation

As indicated earlier, open innovation is a combination of the use of internal and external R&D to innovate. Internal R&D is important for two main reasons, first the company should be able to create knowledge. The company itself must have knowledge to be able to know what requirements the new production process must meet to produce their product. Process innovation needs a deeper understanding of organizational issues, which requires a certain level of knowledge with regard to processes of the receiving company itself. Secondly, to absorb knowledge, external parties can have important technological knowledge that is needed to innovate. To use this knowledge, the company must be able to absorb this new knowledge, which includes interacting with external partners and a learning aspect (Lager & Frishammar, 2010). However, external parties have no insight into the existing knowledge base (tacit knowledge) of the organization (Huizingh, 2011). (Huizingh, 2011). West and Gallagher (2006) challenge the notion of the effectiveness of pure open innovation as a powerful approach to process innovation. The authors indicate that it is not clear whether and to what extent external partners influence process innovation. The potential impact of external support is furthermore limited because, as indicated above, the details of processes are less visible to outsiders.

Building on the knowledge based view, firms are enabled to generate innovation through learning from R&D outsourcing as a practice of open innovation (Un & Rodriquez, 2018). In learning from R&D outsourcing, the firm uses external R&D directly in the innovation of processes. However, to use the external knowledge, a certain level of knowledge of the company itself is required. It is therefore unlikely that there is a direct effect between external R&D and process innovation. This is because there must always be internal knowledge about production processes so that suppliers can be accessed and communicated with them.

As stated before, external parties may offer important technological developments and knowledge that can be used for the realization of process innovations. Absorbing this new knowledge as a company includes learning and interaction with external partners (Lager & Frishammar, 2010). Internal R&D contributes to the absorption capacity of a company, which makes a company capable of assessing, converting and using externally generated knowledge (Schoenecker & Swanson, 2002; quoted in Hung & Chou, 2013). This absorption capacity can be seen as a requirement for open innovation (Huizingh, 2011). By complementing internal knowledge with external knowledge process innovations can be realized. This shows a moderating effect of external R&D on the way in which internal R&D achieves a process innovation. These considerations lead to the following hypotheses, the first focusing on the impact of internal R&D and the second focusing on the impact of open innovation where internal R&D is combined with external R&D:

Hypothesis 1A: The extent of Internal R&D is positively related to the extent of Technological Process Innovation (TPI).

Hypothesis 1B: External R&D positively moderates the relationship between Internal R&D and Technological Process Innovation (TPI).

3.2 Conceptual model

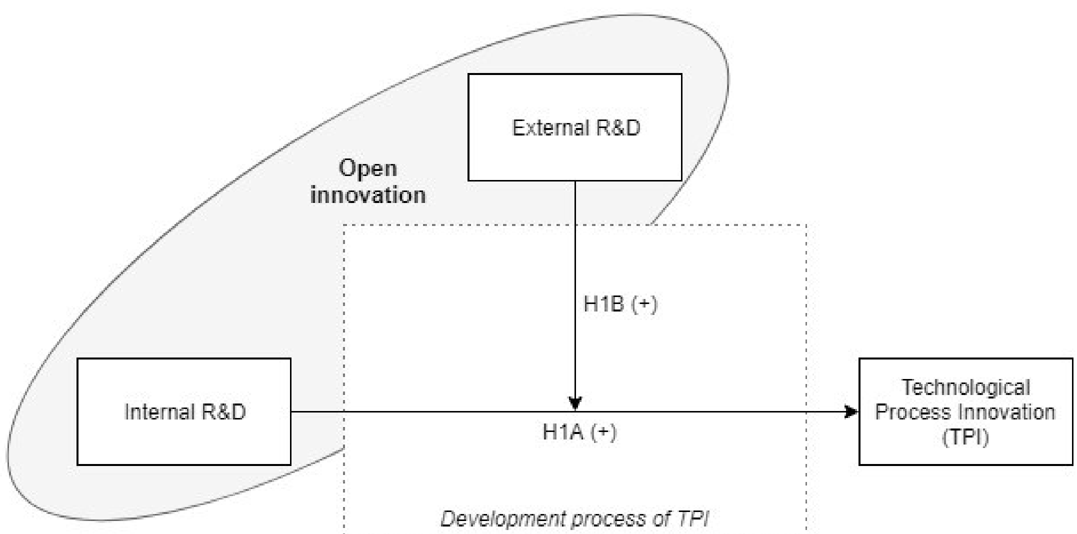

Figure 3.1. Conceptual model relating internal and external R&D with technological process innovation

4 Development process of process innovation

As indicated in the introduction, little research has been done regarding the development process of process innovation. In this chapter, the Stage-Gate model and learning strategies will be explored to elaborate on a possible development process for process innovation.

4.1 Development process of process innovations through the lens of the Stage-Gate model

Innovations require a development process and the Stage-Gate model provides a framework to understand a development process. The Stage-Gate model addresses the development process behind innovation (Cooper, 2008). It describes the innovation process from the moment an innovative idea is born up to and including the moment of its commercialization on the market (Cooper, 2008). According to Cooper (2008, p. 214) "*A stage-gate process is a conceptual and operational map for moving new product projects from idea to launch and beyond – a blueprint for managing the new product development (NPD) process to improve effectiveness and efficiency*". The Stage-Gate model only focuses on product development. The model describes five stages that are preceded by decision moments, also called gates. At these decision moments a management team (the gatekeepers) decides on the basis of as many objective criteria as possible whether the project should be continued, stopped or put on hold. Therefore, at every gate different criteria and activities are applied (see Figure 4.1 and Table 4.1).

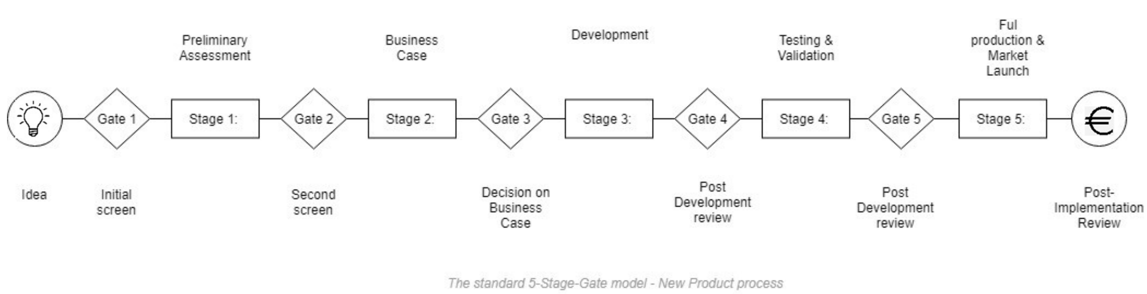

Figure 4.1. Stage-Gate model (Cooper, 2008)

Stages	Activities
Idea/Discovery	The result of this stage is an idea for a new product. There are many ways to raise these new ideas (e.g. research, brainstorming)
1. Preliminary Assessment	In this stage it is determined what the merits of the project are (i.e. technical and marketplace). This stage includes preliminary market, technical and business assessments.
2. Build business case	The result of this stage is a product definition. A project justification and a detailed project plan are made. Therefore, various analyses are done.
3. Development	The result of this stage is a prototype of the product which is tested in-house. Also, among others, the marketing approach, the production plans and the requirements regarding the necessary of production facilities are developed.
4. Testing & Validation	This stage is about testing and validating the entire viability of the project.
5. Full Production & Market Launch	This stage includes the implementation of an operation plan and the launch of the marketing plan.
Post-Implementation Review	This stage involves the evaluation of the project and the product's performance. After this stage the project is terminated.

Table 4.1. Stages of the Stage-Gate model (Cooper, 2008)

The activities and the criteria for decision-making at each stage are based on best practice research. Each consecutive stage is more extensive in terms of time spent and financial investment, which means that at the gates it is increasingly necessary to examine whether the project must be continued further. Even though the Stage-Gate model can be applied to various innovation projects, the characteristics and context of the specific innovation must be taken into account in the development process and implementation (Cooper, 2008; Salerno, Gomes, Silva, Bagno, & Freitas, 2015; Tidd et al., 2005). Given this, the development and implementation of process innovations must be considered in this thesis.

The model has received some criticism concerning the linear representation of the development process, according to Cooper (2008) the process is more complex. The author argues that the process is more iterative and it is possible to go back and forth between the stages among others. The strength of the Stage-Gate model is that it provides a theoretical framework for investigating the development of process innovation (e.g. King, 1992). Moreover, by formulating specific activities per stage, it is possible to assess the parallel or simultaneous work order (McCarthy, Tsinopoulos, Allen, & Rose-Anderssen, 2006).

Concluding, the development of process innovations will be described through the same stages as used for new product development, but the description of the activities will differ. In the development process of process innovation, more attention needs to be paid in particular to the implementation stage (i.e. stage 5), because implementation takes place within the company itself, where learning strategies can play a role in ensuring successful implementation.

4.2 Learning strategies

In the case of process innovation, the implementation of the innovation takes place in the company's own production process. With internal R&D, development takes place within the boundaries of the organization, whereby two different learning strategies can be implemented. Pisano (1996) states that suitable learning methods are essential for the successful implementation of process innovations.

Pisano (1996) focuses on the subject of process development. Based on a 'capabilities based perspective', Pisano (1997) developed a model in which process development projects are seen as attempts to create new process architectures (Figure 4.1). In the case that process development projects were aimed at solving problems related to current production or problems that occur before the process innovation is implemented, this is referred as '*Learning before doing*'. Learning before doing impacts on design (i.e. architecture) and planning, at stages where spending is still at a low level. It makes the process of designing and planning more efficient. Furthermore, improvements made after the implementation of the process innovation, is referred to as '*Learning by doing*'. Learning by doing often interfaces with running production and experiments which requires costly changes of existing machines. The activities that underlie these learning methods contribute to the capabilities of the company to develop processes, which enables the company to use them again for future process development projects.

Concluding, companies should strive for a balance between the strategies learning before doing (e.g. computer simulations) and learning by doing (e.g. experimenting on the production side of a plant) based on the high amount of uncertainty that companies face by the development of innovation processes. This thesis will look at the extent to which companies use these learning strategies, which enables them to successfully implement process innovations.

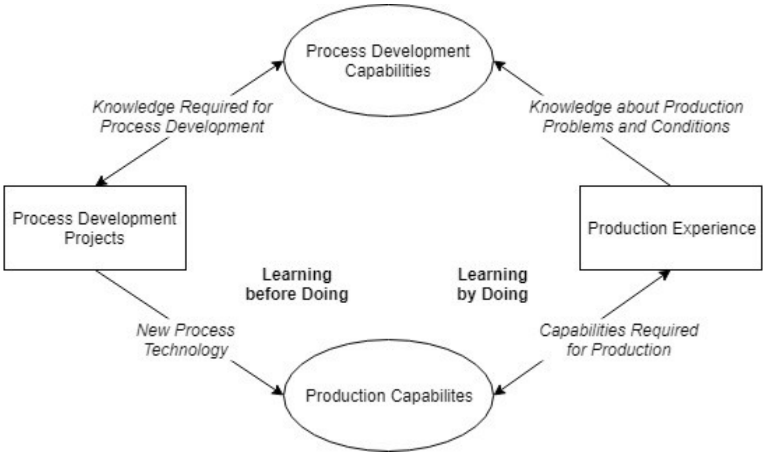

Figure 4.1. A capabilities based perspective on process development (Pisano, 1997)

4.3 Summary

In this chapter the characteristics of the Stage-Gate model and two learning strategies were described (learning before doing and learning by doing). The qualitative part of this study focuses on the activities within the stages and what kind of learning approach the companies that took part in this study use. A development process can be recognized in a few consecutive stages. Prior to a new stage, a management decision moment takes place. The ultimate goal of this thesis is to understand and demonstrate which stages of innovation are relevant in the context of process innovation. In addition, the research required for the development of process innovations relates more to the learning process. The structure of this learning process has consequences for the effective realization of an innovation. Hence, suitable learning methods are essential for the successful implementation of process innovations. Therefore, this study also looks at the use of learning strategies.

5 Research Methodology

To test the hypothesis and gain further understanding about the concepts a mixed method approach is used. The aim of this thesis is to study the relation between internal R&D and process innovation, moderated by external R&D. This chapter elaborates on the research method.

The previous chapters introduced the research problem and described the literature about the fitting concepts. This chapter describes how the research methodology is chosen. Moreover, it also describes how the research is conducted. Other subjects are: data collection, data analysis and research ethics. In addition, the method to measure the independent and dependent variables are explained and the control variables are discussed.

5.1 Research design/strategy

The aim of this study is to investigate the relationships between internal R&D, external R&D (internal R&D combined with external R&D refers to open innovation) and process innovation. The mixed method study combining qualitative and quantitative research is used to identify and explore the relationships between the constructs and to validate hypotheses. In the quantitative study, the generic effects are tested on the basis of the hypotheses. Interviews are conducted on the basis of the survey research, in order to find out more about the underlying mechanics of quantitative results. The advantage of this combination is that the powers of both types of research are combined, with the aim to increase the validity and reliability of the results. The results from both methods can enrich and improve the understanding of the constructs studied (Lopez-Fernandez & Molina-Azorin, 2011).

5.2 Research process/data collection

The required data is collected in two different ways. First, the relationships between internal R&D, open innovation and process innovation were investigated by using quantitative data from the European Manufacturing Survey (EMS). This survey was conducted in 2015. Second, by means of six semi-structured interviews, qualitative information is collected that is complementary and more detailed on process innovation than the EMS (2015) database.

Semi-structured interviews

The main purpose of the interviews was to receive detailed information about the development process of process innovations. The results from the analysis of the EMS data are supplemented and clarified with the help of the interviews. The quantitative results give a generic impression of the hypotheses, hence the interviews were needed to obtain more clarification. The interviews are held at six companies that have the same characteristics as the companies that participated in the survey. Only by interviewing companies with the same characteristics it is possible to meaningfully complement the EMS data with the interview results. Furthermore, the interviews were held in different industry sectors to obtain a balanced palette of respondents.

Firms interviewed			
	Company ID	**Industry**	**Job description**
1	ME	Metal	Lean coach
2	CS	Construction furniture	Production Manager
3	EC1	Electrical equipment	Project Manager
4	MET	Metal/Electrical/Textile	Manager Research Innovation & Product Development
5	EC2	Electrical equipment	CEO
6	MC	Machinery	Lead Engineer

The interviews were semi-structured, meaning that key questions about the concepts were prepared in advance (Bleijenbergh, 2015). These key questions were noted in an interview script and can be found in Appendix II. The questions are about how and to what extent the concepts are applied and experienced. The interview was structured on the basis of the following main topics: 1) Process innovation; 2) Internal R&D activities; 3) External R&D activities; 4) Open innovation activities; 5) Development process of process innovation.

To get more clarity about the steps involved in the development of process innovations, the interview script includes questions referring to the order of the stages and gates of the Stage-Gate model. The qualitative data used in this research are collected by interviewing employees, who are active in the departments: R&D, Engineering or production. The employees should preferably have been with the company for at least two years, with the company preferably employing at least 50 full-time equivalent employees. In this way it can be assumed that this employee has observed the developments in the company in the fields of process innovations and open innovation.

The information from the semi-structured interviews are coded in two ways. First, the data was coded theoretically. This identifies what the interviewee understands by the research concepts. Secondly, the data on every topic was openly coded. The purpose of this was to gain insight into what is happening in the relationships as existing in the conceptual model (see paragraph 3.2). In addition, it was examined which factors are mentioned in this relationship.

European Manufacturing Survey

The quantitative data that is used for this thesis is taken from the EMS (2015). The questionnaire was prepared, among others, by the Institute for Management Research of Radboud University Nijmegen. The EMS survey was conducted in 2015 by using an extensive questionnaire surveying 277 Dutch and Spanish manufacturing companies having 10 or more employees (Ligthart, Vaessen, & Dankbaar, 2008; Appendix III) The aim of the EMS (2015) is to map the innovativeness of the manufacturing industry. In other words, to gain insight into the innovation of production processes. The analysis in this study is limited to Dutch manufacturing companies. Based on the EMS database, the hypotheses formulated in chapter 3 are validated. A linear regression analysis is chosen to conduct an analysis of the quantitative data.

5.3 Operationalization

To conduct the research, the concepts from literature were made measurable. In the European Manufacturing Survey (EMS) indicators were found for the topics 'open innovation', 'internal R&D', 'external R&D' and 'technological process innovation'. For some topics it was needed to transform the questions to come to concepts. The items/indicators that were used to measure the concepts are presented in Appendix III. Later in this chapter, both the validity and reliability of the concepts are discussed.

Dependent variable

Technological Process Innovation

The dependent variable of this thesis is the extent to which a company has applied innovative technologies in its production processes. The process innovations were measured based on the number of technologies used in a company. The more technologies a company has applied, the more innovative a company is. It is a proxy variable, because it counts the number of technologies applied in a firm, calculates its average, leading to a firm-level value.

Independent variables

Internal R&D

To cover the concept of internal R&D, this thesis uses the percentage of employees in a company involved with R&D activities.

The interviews have to clarify what kind of internal R&D activities the company does. These activities should meet five core criteria. The activity have to be: "*novel, creative, uncertain, systematic and transferable and/or reproducible*" (OECD, 2015: p28). These 5 criteria are used to indicate whether it concerns an R&D activity.

External R&D

To cover the concept of external R&D, it is examined what the external R&D intensity is in a company. First of all, the percentage of R&D activities performed by own staff is taken into account, which is based on question 1.5 of the EMS survey (2015) (Appendix III). Subsequently, only the companies that have indicated that they perform R&D activities were selected (i.e. R&D active), regardless of whether this is performed internal or external. Hence, the variable external R&D is based on the percentage of companies that are R&D active minus the percentage of companies that have their R&D activities performed by own staff. In this way the variable external R&D can be seen as a reverse variable.

Control variables

It is important that control variables are included in this study. A control variable can be described as a variable that should be included in the study but that is not specifically addressed. These control variables must be included because they affect the dependent variable and also relate to the independent variables.

Firm size, industry

Organizational characteristics can influence strategic choices with regard to innovation activities. These characteristics are represented in control variables that are related to the dependent variable, but in which the researcher is not particularly interested. First, it controls the size of the company. Previous studies have shown that the innovation strategy relates to the firm size (e.g. Vossen, 1998). Some even show a positive relationship between company size and innovation (e.g. Rogers, 2004; Ayyagari, Demirguc-Kunt, & Maksimovic, 2012). The company must be a small and medium-sized company. This is an interesting research group because smaller companies often have insufficient availability of resources, financial resources and capacities for production, distribution and marketing (Bianchi, Campodall'Orto, Frattini & Vercesi, 2010). In other words, based on the amount of available resources, this is an interesting group to investigate. The firm size is measured by the number of FTEs employed by a company, with a minimum of 10 employees and a maximum of 250 employees. The second control variable is the industry sector. Only sectors of the Manufacturing Industry were investigated. The Hague Centre for Strategic studies and TNO

(2013) found in their study that R&D activities do not take place evenly across the market sectors. Hence, the R&D intensity varies per sector. The purpose of checking for company size and industry sector is to remove their effects from the equation. In this research it is possible that the companies that realize process innovations are different when looking at the firm size or industry sector.

Moderating effect

A moderating effect is a variable that affects the relationship between the independent and dependent variable (Baron & Kenny, 1986), which refers to an interaction effect. In this study is assumed that there is an interaction effect of external R&D on the relationship between internal R&D and process innovation. Therefore both variables are mean-centered and multiplied by each other in the analysis. This interaction effect refers to an open innovation approach. Here the degree of internal R&D and external R&D was examined.

In order to gain more in-depth understanding of open innovation, the eight different activities formulated by Van de Vrande et al. (2009) were asked during the interviews (Appendix I). The interviews have to clarify the precise kind of open innovation activities by asking for two types of practices concerning External Technology Acquisition (ETA) and External Technology Exploitation (ETE) practices (Van de Vrande et al., 2009).

Data analysis

For this study, the method of data analysis is a multiple regression. This regression analysis examines the relationship between the independent variables 'internal R&D' and 'external R&D' to the dependent variable 'process innovation'. For this analysis it is checked if all assumptions were met. Moreover, a reliability and validity analysis is done.

Data preparation

To arrive at a good estimate of the regression coefficients by means of linear regression, it is important to check the underlying assumptions (Field, 2013). This is because violated assumptions can have implications for the statistical results.

Missing values. The dataset was checked for missing values. The total dataset exists of 177 observations. According to Hair, Black, Babin & Anderson (2014) the rule of thumb is as follows: <10% missing values for each individual case of observation. Three respondents have not answered all questions of the EMS survey, therefore inconsistencies arose when analysing the EMS results. By excluding these respondents, the analysed dataset reduced to 174 observations.

Metric scale. All variables need to be of metric scale, therefore a dummy variable is generated. The categorical variable was firm industry, which was binary and transformed into a dummy variable.

Normality. There is assumed that the errors in linear models are normally distributed (Field, 2013). This means that the shape of the error distribution for each metric variable is normally distributed (Hair et al., 2014; Field, 2013). Therefore the control variable 'Firm size' was logarithmic transformed into the variable 'lnSize'. By transforming this variable, the strong right skewed distribution was corrected. Skewness was 12.731 and after transforming the skewness was 1.490.

Linearity. The dataset is checked for the assumption of linearity. In linear models linearity is assumed as correlations that represent the linear relation of the variable (Hair et al., 2014). To assess the assumption of linearity a scatterplot is used. A straight line can be drawn through the point cloud in the scatter plot, therefore no additional transformations were performed. The scatterplot can be found in Appendix IV.

Homoscedasticity. This means that there has to be a constant range of error terms of an independent variable. The scatterplot shows that the outcomes are sufficiently divided over the plot without a clear pattern in the residuals, and therefore are unbiased and homoscedastic. The scatterplot can be found in Appendix IV.

Multicollinearity. To check for multicollinearity, the collinearity statistics in the coefficients table were studied. All Tolerance values are above the value .20. This means that there is less multicollinearity.

Independence of the error terms. The error is part of the variance that cannot be explained by the independent variable. By looking at the Standardized Predicted Value it can be said that the mean equals 0.00 and the standard deviation equals 1.00. This means that the errors do not correlate with the independent variables. The table named Residuals Statistics can be found in Appendix IV.

5.4 Reliability/Validity

In this section the concepts of reliability and validity are described. The quality of the research is determined by these concepts. In addition, research ethics is described.

Reliability

Reliability can be defined as "*the degree to which the observed variable measures the true value and is error free*" (Hair et al., 2014, p. 8). In other words, the reliability of the research results indicates to what extent the research is free of chance. Measures will be taken in this investigation to prevent the occurrence of accidental errors.

A reliability analysis was conducted in SPSS for the variable Technological process innovation. The reliability has been assessed using Cronbach's Alpha test. This tests the internal consistency of the questions from the survey. For Cronbach Alpha, the generally accepted value for scale reliability is 0.7 (Field, 2013). The question about technological process innovation consist of eighteen items and together form a Cronbach's Alpha of .681 (α=.681, 18 items, N=177), which is lower than the advised value of .7. Research shows that the removal of an item does not significant increases the Cronbach's Alpha. It has been decided not to delete any item in order to continue to guarantee the content validity. However, according to Cortina (1993), the Cronbach's Alpha above 0.6 is also acceptable. Therefore, it can be concluded that the internal consistency of the question is acceptable. The SPPS output of the reliability analysis can be found in Appendix IV.

Validity

The validity can be defined as "*the degree to which a measure accurately represents what it is supposed to*" (Hair et al., 2014, p. 7). It indicates to what extent the investigation is free of systematic errors. The idea behind this is that the research method provides the right information in the desired quality that is needed to answer the research question. The following three forms of validity are considered (Yin, 2003):

Construct validity. According to Yin (2003) this can be described as whether the appropriate operational measures are established for the concepts under research. In this study, all research variables are measured by a single item.

Internal validity. According to Yin (2003, p. 34) this can be defined as "*establishing a causal relationship whereby certain conditions are shown to lead to other conditions as distinguished from spurious relationships".* By using control variables, it was tried to minimize systematic error or bias to better understand the main conceptual relations.

External validity. According to Yin (2003, p. 37) this can be defined as "*to generalize a particular set of results to some broader theory*". As a total of six respondents from different industry sectors were interviewed, the external validity can be questioned. For this reason it will be emphasized that the interviews will only serve to provide a more in-depth understanding of the relations between the concepts. The quantitative analysis can serve better to generalize the results to the population.

The combination of quantitative and qualitative research methods in a single study enhances the validity of the research due to triangulation. This refers to the use of more than one method while studying the same research question (Hesse-Biber, 2010).

Ethics

Throughout the research, the code of conduct of the American Association for Public Opinion Research mentioned in Babbie's book (2013) is considered. Prior to the interviews, the usefulness of the research was explained to the respondent. It was also explained what role they play in this research. Respondents were asked to participate in the survey on a voluntary basis by freeing up an hour of their time. The information that is emerged from the interviews is only used for this research. The responses are also made anonymous to ensure privacy. All answers are treated in strict confidence. The interview transcripts were sent to the respondents for validation. In this way, wrong interpretations and misunderstandings of the results are reduced.

6 Results

Quantitative and qualitative research techniques were used to answer the research question. In this chapter, the results of the quantitative, linear regression analysis and qualitative methods, semi-structured interviews, are presented. The first part of the chapter is aimed at the presentation of quantitative analysis. The second part of this chapter presents the results of the theory-guiding coding of interviews conducted.

6.1 Quantitative analysis

As stated before, there is chosen to conduct a linear regression analysis in which two explanatory variables were used to predict the dependent variable.

6.1.1 Descriptive statistics

The quantitative data comes from the European Manufacturing Survey (2015). This fulfils the requirement that this research only concerns companies that are active in the manufacturing industry. In addition, this research focuses on Dutch small and medium-sized businesses. The European Commission applies a maximum of 250 employees to distinguish small and medium-sized businesses. An overview of the descriptive statistics can be found in Table 6.1. Information on correlations between variables can be found in Appendix IV.

Firm size. Since this study strives to give a good impression of the manufacturing industry in the Netherlands, some large companies (e.g. outliers) have also been included in the study. As a result, the firm size range is 7790 employees, with a minimum of 10 and an average size of 104 (M=104.040; S.D.=591.003) This leads to the inclusion of 174 companies, which in turn are spread over seven industry sectors.

Industry sector. Most companies are active in the Metal, Electronic or Machinery industry sectors, while the Construction and Food sectors are the least represented. An overview of descriptive statistics can be found in Table 6.1.

Technological Process Innovation. Research shows that, on average, firms implement 3 technologies (M=3.833; S.D.=2.656; N=174), which is around 16.67% of the total of eighteen process technologies mentioned in EMS (2015).

Internal R&D. Internal R&D refers to the percentage of R&D activities that a company has performed by its own staff. To determine the extent of internal R&D at companies, the number of R&D employees was examined. Results of the EMS (2015) shows that 43 out of 177 companies have indicated that they do not employ R&D staff (24.3%), implying that the same percentage is valid for the 174 companies included in the statistical analysis. The remaining companies indicated to have between 1 and 25 R&D employees. On average, firms have 5 R&D personnel (M=5.543, S.D.=5.749, N=174).

R&D active. R&D active refers to the percentage of companies that have indicated that they carry out R&D activities, regardless of whether they take place internally or externally. The EMS results reveal that 86.78% of the companies perform R&D activities (Table 6.1).

External R&D. External R&D refers to the percentage of companies that outsource their R&D activities to external parties. The companies that can be counted as R&D active form the total number of companies that carry out R&D activities (R&D total). R&D Total is set at 100%, which corresponds to 151 companies (0.8678 * 174 = 151.00). External R&D is calculated by subtracting the percentage of R&D activities performed by own staff from the percentage R&D Total (i.e. 100%). The EMS results reveal that 38.60% of companies have their R&D activities carried out by external partners (M=38.598, S.D.=37.249, N=174).

Table 6.1. Descriptive statistics (N = 174)

Variable	Mean	Std. Dev	Min	Max
Technological Process Innovation	3.833	2.656	.00	10.00
lnSize number of employees	3.702	.928	2.303	8.962
Industry:				
Food	.103	.305	.00	1.00
Textile	.130	.333	.00	1.00
Construction	.075	.264	.00	1.00
Chemical	.130	.333	.00	1.00
Machinery	.180	.384	.00	1.00
Electronic	.178	.384	.00	1.00
R&D active	.868	.340	.00	1.00
Internal R&D	5.543	5.749	.00	25.00
External R&D	38.598	37.249	.00	88.00

Note. The metal industry is the reference category for industry.

6.1.2 The model

Linear regression analysis is used to study the relationship between the dependent variable and the independent variable. In the research design this means that the number of process technologies in a firm is influenced by the independent variables 'internal R&D', 'external R&D', and the control variables in the first model tested. In the second model, the moderating effect of 'external R&D' on the relation between 'internal R&D' and 'process innovation' is analysed.

6.1.3 Linear regression analysis

The multiple regression that was conducted comprised the dependent variable, independent variables and control variables, using a four steps enter-method. Model 0 shows only the dependent variable. Model 1 includes the effects of the control variables industry and firm size. Model 2 contains all previously mentioned variables and independent variables internal R&D, external R&D, RD active. At last, Model 3 contains all previously mentioned variables and the interaction effect (Table 6.2).

The null hypothesis is tested by means of ANOVA. It is checked whether there is a connection between the variables. Table 6.2 shows that all three models are significant. In other words, the regression model contains significant explanatory variables.

Table 6.2 Effects regression results

Model (DV = Technological Process Innovation)	1	F(7,166)=12.068	2	F(10,163)=8.389	3	F(11,162)=7.608
	Coef.	*p* Value	Coef.	*p* Value	Coef.	*p* Value
lnSize number of employees	1.602 (.185)	.000	1.599 (.186)	.000	1.604 (.187)	.000
Industry:						
Food	-.375 (.638)	.558	-.399 (.650)	.541	-.413 (.652)	.527
Textile	-.747 (.595)	.211	-.705 (.602)	.243	-.714 (.604)	.239
Construction	.071 (.717)	.921	.065 (.730)	.929	.049 (.733)	.947
Chemical	-.582 (.596)	.331	-.547 (.604)	.367	-.550 (.605)	.365
Machinery	.379 (.543)	.486	.448 (.555)	.421	.449 (.557)	.421
Electronic	.582 (.537)	.280	.620 (.552)	.263	.603 (.554)	.279
R&D active			.123 (.602)	.838	.216 (.637)	.735
Internal R&D			-.006 (0.033)	.861	-.006 (.033)	.855
External R&D			.003 (.005)	.568	.003 (.005)	.563
InternalR&D*ExternalR&D					.000 (.001)	.652
Constant	-2.067 (.745)	.006	-2.271 (.859)	.009	-2.358 (.883)	.008
Observations	173		173		173	
R^2	.0337	.000	.340	.891	.341	.652

Note. The metal industry is the reference category for industry.

**p<.05, **p<.01, ***p<.001*

6.1.4 Hypotheses

Table 6.2 summarized the results of the regression analysis.

First, the influence of internal R&D was conceptualized. Internal R&D could have a positive effect on technological process innovation, resulting in the following hypothesis: *Hypothesis 1A. The extent of Internal R&D is positively related to the extent of Technology Process Innovation (TPI).* The results of the linear regression analysis (see Table 6.2) show that internal R&D does not have a significant effect on the number of technologies (B= -.006; *p*=.855). Hence, hypothesis 1A is rejected.

Second, the influence of the interaction term between internal R&D and external R&D was conceptualized. External R&D could have a moderating effect on the relation between internal R&D and the number of technologies. This resulted in the following hypothesis: *Hypothesis 1B: External R&D positively moderates the relationship between Internal R&D and Technological Process Innovation (TPI).* The results of the linear regression analysis (see Table 6.2) show that the interaction term internal R&D-external R&D does not have a significant effect on the number of technologies (B=.000; *p*=.652). Hence, hypothesis 1B is rejected. From this it can be concluded that open innovation in the form of a combination of internal R&D with external R&D has no significant influence on technological process innovation.

In addition, the control variable size, which was significant has an influence on the number of technologies (*p*=.000). The control variable Industry was not significant, which means that it does not matter to which sector a company belongs. In other words, all sectors do not score significantly on the number of technologies.

6.1.5 Summary

The formulated hypotheses were tested on the basis of quantitative analysis. The construction of internal R&D appeared to have no significant influence on the dependent variable, just as external R&D. Although the quantitative method provided insights into the existence, strength and direction of relationships, the following section provides insights into the content of relationships. In this qualitative analysis, quotes from six different respondents were analysed.

6.2 Qualitative analyses

To gain insight into the question why companies do R&D activities internally or outsource them to an external party in order to jointly realize technological process innovations, six semi-structured interviews were conducted. These interviews were conducted at companies that were similar to the respondents (i.e. meeting the same criteria) who participated in the European Manufacturing Survey (2015). All interviews were conducted with audio recording equipment and then fully transcribed. This made it possible to thoroughly analyse the interview and to correctly formulate quotes. By first coding on the basis of the theory, the most relevant quotes from the respondents about the concepts were selected. The findings will be discussed in the following sections. The rest of the chapter is structured as follows: first the concepts process innovation, internal R&D, and external R&D/ open innovation are discussed. Second, the development of process innovation is described through the lens of the Stage-Gate model, whereby the inter-concept relations become clear. Third, the findings of the qualitative analysis will be described in a short summary. Finally, both analyses will be cited again to formulate concluding words about the analyses with regard to the conceptual model.

To make coding more structured, use has been made of various categories such as purpose, reason, partnerships and activities. All categories used can be found in Appendix V.

6.2.1 Main concepts

The following main concepts can be distinguished: process innovation, internal R&D and external R&D/open innovation. Although the quantitative part showed no significant relation between the constructs, this qualitative part will be used to explore the development process of process innovation. The Dutch translation of the quotes that are used can be found in Appendix V.

Process innovation

The first main concept is process innovation. In this study the emphasis is on SMEs that innovate their production processes by introducing new machines. The results indicate that a process innovation is not a standalone goal on itself. Below two interrelated drives of process innovation are explained.

Process innovation as result of product innovation. The respondents indicated that they implement process innovations to facilitate product innovations. In other words, the production line is adapted as a result of product innovation. As an example: "*if we have a new product innovation, so a successor from boiler A to boiler A +, then it may be that a number of operations change to assembly. So you have to look at your actions. That can mean that you will take a different approach* (ME)" (Table 1). Another example is "*Here we will develop a production line for recyclable mattresses. We will replace all our mattresses with recyclable mattresses. This is a* *new production process that does not yet exists.* (MET)" (Table 1). Hence, the production of a new product often requires a company to innovate, for example to include new production steps that cannot be provided by the current production line.

Process innovation to improve efficiency. After a new production line is implemented, the production line is further assed to improve efficiency, which results in process innovation. Respondents described it as "*which actions are repetitive? Which actions are ergonomically not justified? We have quite a bit of heavy products. Can't you use applications with that* (ME)?" (Table 1). Another example is "*you focus more on how you can fine-tune the process. You do that by focusing on the process and timing it with a stopwatch. In the event that people have to start puzzling, a production step takes just 4 or 5 seconds longer. You will investigate which simple tools you can add to the process so that people no longer have to think.* (EC1)" (Table 1). Another respondent said "*Because what you also see is that we first go live and then we see additional potential to organize our production more efficiently. So that often comes after that.* (ME)" (Table 1).

Concluding, process innovations are needed at the introduction of new products. After a process innovation has been implemented, often additional innovations are realized to improve efficiency.

External R&D as an extension of internal R&D

In the theoretical framework it was explained that internal R&D relates to R&D activities that are carried out by own personnel in a company. External R&D relates to R&D activities carried out by an external party. The findings demonstrate that in SMEs external R&D can be seen as an extension of internal R&D.

Internal R&D. The results demonstrated that for the purpose of a product innovation companies often design and improve their production line themselves. Similarly, requirements for machinery needed for the product innovation are also formulated. This is the role of internal R&D. As indicated in the theory the role of internal R&D is invaluable in these processes as they are most familiar with the tacit knowledge base of the company. One respondent said "*we design the whole line, so we monitor the machinery. But dedicated machines are designed by the suppliers* (MET)" (Table 2). Another example is "*We have production engineers who make production lines. When creating a production line, more knowledge is needed compared to the production staff who only* *assemble products*. (EC1)" (Table 2). In addition to designing their own production line, various respondents emphasized that they did have knowledge about how the machines work, "*we have the knowledge of how he machine works exactly* (MC)" (Table 2). Another example is "*I have worked in machine factories so I know technically how all those frequency converters and electronics work. I know how the machines are controlled and by which machines and applications*. (CS)" (Table 2). Respondents refer here to the tacit knowledge base of the company, developed through internal R&D activities. This knowledge is used for example when formulating technical requirements for a new production method.

External R&D. However, to realize process innovation SME companies depend on external R&D. The main reason for this is cost efficiency, developing new machinery is not part of their core business and is therefore outsourced. Nevertheless, to ensure that the machinery developed by the external party meets the requirements of the internal organization, the combination of internal R&D and external R&D is a key success factor.

One of the respondents stated "*the moment you have to develop a machine that has to be placed in your production line, you stray from your core business.* (EC1)" (Table 3). Another example is "*As a company, we are growing so fast that we had to outsource certain R&D activities. This allowed us to focus more on our tasks. As a result, we are now only focused on doing what we are good at, developing new boilers.* (ME)" (Table 3). Most companies do not have the resources to develop a machine themselves, "*We have chosen to have it developed externally because we do not have the right resources to do it ourselves.* (CS)" (Table 3). Outsourcing certain activities saves companies costs, "*Some things are outside your own competence. Suppose you need certain sensors that can help you make the process run better. Well electronics is not our thing so we outsource that. It is also simply cheaper to outsource it.* (MC)" (Table 3).

Open innovation. As indicated above, in SMEs innovation is typically realized through the combination of internal and external R&D. In the literature this is referred to as an open innovation approach. Of the open innovation practices that Van de Vrande et al. (2009) distinguishes (Appendix I) three are identified by the respondents, namely involvement of non-R&D workers (ETE), outward licensing of intellectual property (ETE) and R&D outsourcing (ETA).

In the case of **involvement of non-R&D workers**, a respondent stated, "*Knowledge of production staff is also used, because we can think that it is all easy, but sometimes there is just a little nod in the production process.* (EC1)" (Table 4). Another example "*When making a prototype, as many people as possible are involved who will eventually make the product. In this way you can* *also include their comments in the development*. (MET)" (Table 4). These examples show that knowledge is used from employees, who are not employed by the R&D department, to realize a process innovation.

An example of **outward licensing of intellectual property** "*We must ensure that our competitors also start selling these mattresses so that volumes go down and the cost price too, and then we are competitive. So we need competitors. We are now actively visiting our competitors to ask if they also want to supply these mattresses. We are open to competitors who want to copy the production line that we have developed* (MET)" (Table 4). In this example the company wants to benefit from his own intellectual property by letting other companies make use of their knowledge of producing by selling or offering licenses/patents to them.

In the case of **R&D outsourcing**, one of the respondents stated "*In the event that a completely new production step has to be incorporated in a production line, a step of which the production engineers have insufficient knowledge, then you try to find a solution on the market. Then we look for a partner who can help us.* (EC1)" (Table 4). Another example is "*we design the whole line, so we monitor the machinery. But dedicated machines are designed by suppliers.* (MET)" (Table 4). These examples show that certain R&D activities are outsourced to other organizations to acquire external knowledge.

Concluding, when realizing process innovations, only three of the eight open innovation practices can be identified. It was characteristic that two of these three practices, involvement non-R&D workers and outward licensing or intellectual property, belong to ETE activities. This suggests that the generation of internal knowledge and R&D outsourcing play an important role in the realization of process innovations. However, by realizing product innovations, six out of eight practices can be identified, with only the practices of external participation (ETA) and venturing (ETE) not being identified. This suggests that several ways of acquiring knowledge can be used for the realization of product innovations, but only a few open innovation practices can be useful for realizing process innovations.

To summarize the sections above the following can be stated. A combination of internal and external R&D activities are required to realize process innovation, this combination is also referred to as open innovation. In the literature open innovation is described in the context of product innovation. The findings demonstrate that when the open innovation approach is applied to process innovation, the activities involved are only partially identified, specifically: non-R&D workers (ETE), outward licensing of intellectual property (ETE) and R&D outsourcing (ETA).

6.2.2 Development process of process innovation

As stated before, the original Stage-Gate model from Cooper (2008) focuses on product innovation. This model may be adapted to apply to process innovation. This qualitative part of this report discusses for each stage of the model the adaptations that are needed. It is assumed that the product will receive more attention in the first stages and that in the later stages the emphasis will increasingly be on the process.

Stage 0. Idea/Discovery

The above section regarding process innovation has shown that process innovation ideas stem from product innovations. Product innovations are often conceived based on customer needs. As an example "*The end users give a specific specification of what they want. We will then make something that meets those specifications.* (EC1)" (Table 5). Here the attention is usually focused on coming up with a new product. But also government policy and innovations at suppliers can lead to new ideas, both for the product and the process. An example with regard to government policy is "*The Netherlands is currently dominated by 'less gas', based on government policy. But that also impacts our company of course. This means that we also have an innovation department for this that, together with our sister companies, to think about such matters.* (ME)" (Table 5). An example of a suppliers trade show is "*But in particular we are not surprised by the standard branch fairs so we visit many fairs from other sectors. For example, winter sports fairs or architects fairs where we may discover new materials for our products. In my opinion very small steps are always taken in a sector. But if you are going to apply techniques from another sector in your own sector, you can suddenly take a very big step* (MET)" (Table 5).

The interviews give the impression that ideas for innovations arise in an unstructured way. In this stage the project has not yet begun, a respondent described it as "*it is a little more open-ended, a creative process* (MET)" (Table 5). Hereby all employees of the company can contribute their creativity and expertise. This makes it difficult to make a systematic description of this stage.

Stage 1. Preliminary Assessment/ proposition phase

After it has been determined that the idea is promising for future production, it is worked out and a cost price is estimated. To be able to determine the cost price, it is considered at an early stage how the idea can be realized, "*because otherwise you cannot estimate what the cost price could be. But in the proposition phase it is a very rough estimation* (MET)" (Table 6). This implies that in stage 1, the production method already needs to be considered. In this phase a project plan is written, "*at the end of the proposition phase, you have everything clear to write a project letter*

(MET)" (Table 6). The project plan describes globally what the project entails with the estimated cost price, with the aim of being able to decide whether the project should be started. The quotes showed that each company describes different functionaries that are involved writing a project plan. For example, it appeared that one respondent described it as "*That is a product manager in most cases and a proposition designer. The two actually work it out together. They also involve other disciplines, but they do not really form a project team that meets every week with a pull board and monitors a schedule.* (MET)" (Table 6). This stage ends with, "*well then the project leader has to present it and then management determines whether he can continue in that gate. That is then a real 'go' or a 'no go' to start the next stage* (EC1)" (Table 6). This indicates that this stage requires a more formal approach. To enter the next stage the company's management decides if the project can start, "*and then after the proposition gate, such a project really starts. Then it gets status in the organization. And then the project team is really in the lead. But this really the gate that management says "that proposition is indeed interesting and we will do it or we will not do it"* (MET)" (Table 6).

Stage 2. Build business case/ concept phase

This stage the start of the project with regard to new product/process development. After the approval of the project plan, a business case is made. Considering a process innovation this regards a cost-benefit overview. In this stage the project plan has to be elaborated, "*In the concept phase you actually made all the difficult decisions. Then your cost price is largely determined, because you have already devised your technology and production process in concept.* (MET)" (Table 7).

Often a test specimen is built that is intended to serve as proof of concept. It is examined whether the intended production techniques actually fall within the cost price, "*we have three possible interpretations of technology for the product and this is the best. The management does not decide that, because the project team decides. As long as it matches the agreements in the project letter.* (MET)" (Table 7). If it turns out that a new production step is needed, the help of a supplier is required. As an example "*Here is a glue machine that must work with a type of glue that we have developed together with a supplier. We had to convert and test this machine ourselves. The results served as proof of concept. Only then could we discuss with a supplier what kind of machine we needed for that*. (MET)" (Table 7). The conversion of an existing machine for testing the new glue requires internal R&D activities. One of the respondents said "*All your supplier choices have already been devised in the concept phase* (MET)" (Table 7). In this stage, particular attention is paid to "*is the potential good, is the market price good, is the cost price good? If so, then we can continue*. (EC1)" (Table 7). It was notable that one of the respondents indicated that the composition of the project team changed during the project, "*it depends on what stage the whole project is in, that part of the project team will come together. And gradually, third parties may come along once. But so at an early stage, there is a whole team* (EC1)" (Table 7). It therefore depends on the progress of the project which employees and external parties (e.g. supplier) are involved in the project.

Stage 3. Development

At the end of this stage a final prototype of the product is made. As this study focuses on process innovations, the development of the prototype with regard to product innovation is not discussed. A new production line is not yet needed to produce this prototype. After designing the prototype, it is made and tested "*it is just put together loosely and it is ensured that it works. That it does not look nice at all, does not matter* (EC1)" (Table 8). Once the prototype has been made, "*at that early stage, the company itself is able to unravel that new product, so that production engineers can properly define those different production steps* (EC1)" (Table 8). Another example is "*then the production is involved and the manufacturability of the item is considered.* (ME)" (Table 8). Both examples show that the production engineers examine for each part how it should be produced. One of the respondents said "*most companies think functional first, but in an early stage you already have to think about how to make it and what production steps are involved* (EC1)" (Table 8). After the prototype is made, it is determined which technical requirements the production process must meet. It was noticed that all respondents discussed a certain sequence of production steps, "*we have a certain way, a certain sequence of production in our production process* (ME)" (Table 8). At the end of the development stage, "*there must already be a very clear impression of what the new production line will look like. But also if we have to make an adjustment to the current production line production line, what do we have to adjust?* (ME)" (Table 8). Several respondents have indicated that they design their own production line and manage their own machinery. They know exactly the order of the production steps, implying that they know which action must be done and when. When it appears that a new production step is needed, other companies are contacted to find a solution. As an example "*In the event that a completely new production step has to be incorporated in a production line, a step of which the production engineers have insufficient knowledge, then you try to find a solution on the market.* (EC1)" (Table 8). The interviews showed that all respondents were outsourcing the development of a new machine. But internal R&D activities are required to come to a suitable machine together with the supplier. The company will request quotations from several suppliers, "*if you know that someone else can do it too, then you will compare the offered prices and solutions* (MET)" (Table 8). Regarding the choice of a suitable supplier, the findings revealed that the companies have preferences based on previous experiences with a supplier at previous deliveries. When looking for a supplier, one of the respondents indicated "*if the product delivered by a supplier is that good and suited to fit it into my production system, then this supplier has a good chance that he also will provide the follow-up machines* (CS)" (Table 8). This example shows that favourably the system of one machine must match the other machines in the company. The reason given by the respondent for this was "*it is of course also great for your operators in your organization that you work with one system* (CS)" (Table 8). Another respondent indicated that they also select suppliers based on the service that they can provide with the machine, "*But can they also provide service? Can they also provide maintenance? You have to take all these aspects into account, because you cannot do the maintenance yourself because it is all new to you* (EC1)" (Table 8).

The findings show that different functionaries are involved in the purchase of a machine. One of the respondents stated "*It is usually carried by a technical person and supported by, for example, purchasers or people from the planning because they receive all inputs about what requirements it must meet.* (MC) "(Table 8). Another respondent stated "*It is often the purchaser, a tool project manager, a product developer of the team and the supplier who ensure that the machine can do everything to make every product.* (MET)" (Table 8). These examples show that it is often a combination of a purchaser and an employee with technical knowledge (e.g. process engineer, production engineer, mechanical engineer).

For SMEs, this type of order (i.e. purchasing a machine) often involves enormous amounts of money and time. Therefore, the provision of the order in SMEs will usually be the gate to the next stage. One of the respondents indicated "*Buying such a saw is not something you do on a Monday morning. It is a process of 2, 3 or 4 weeks intensive in terms of hours* (CS)" (Table 8). Another respondent described it as "*At the end of the development phase you have all your drawings final, all your quotes final for tools and such. Then you say: this is the point of no return. If we go now, we will make all investments. So if we say "yes" then the investments are made and then you go to the realization phase.* (MET)" (Table 8). Another respondent also recognized the point of no return, "*You have a certain point of "no return". That is often when there are samples already and the first tests have been done and we believe that it is a promising product*. (EC1)" (Table 8). Stage 3 ends when the supplier accepts the order to deliver the new machine. In the next stage, the supplier will develop the machine. In addition, the quotations of the supplier also contain global agreements on how the machine will be tested. These tests will be specified in detail during the next stage. As an example "*You actually always agree in advance what you want to test. So, for example, do you want to do a general test? Or do you want to make a very specific customer* *product? Do you want to approve the machine after the production of one or after ten, after one hundred items?* (MC)" (Table 8).

Stage 4. Testing & Validation

After the supplier has accepted the order, he will also refine the agreed tests together with the development of the new machine. Ideally, a specific test is assigned to each requirement. This means that the development of the machine runs parallel to the preparation of the test plan. Typically, the company accepts the machine after two tests are performed, the Factory Acceptance Test (FAT) and the Site Acceptance Test (SAT).

During this stage, the company is given the opportunity to make changes if the requirements are not met. The quotes showed that people who normally work on the production line are involved by the development of the machine. The reasons that were mentioned are "*the nice thing about it is that you also involve the people who ultimately have to assemble that product. And what we often underestimate, perhaps still, is that there is a lot of knowledge there.* (ME)" (Table 9) and "*Knowledge of production staff is also used, because we can think of 'it is all easy' but sometimes there is just a little nod in the production process* (EC1)" (Table 9). The purpose of an FAT is to qualify the equipment prior to shipment to the customer. During the FAT the supplier and customer are present. As an example "*If the supplier indicates that the machine is ready, I will visit the factory. The machine is then completely set up and put into operation. Then I go sawing planks all day*. (CS)" (Table 21). One of the respondents indicated to that they involve the employees of the production department by this test, "*I sometimes take a production employee with me.* (CS)" (Table 9). The respondent indicated that he wanted to be present during the testing to be able to check whether he was getting what he wanted, "*I check whether the machine meets all requirements. The moment I am convinced that that is the case, I put a signature.* (CS)" (Table 9). If a problem arises, the parties must meet again to discuss how the situation should be addressed and to decide whether the current operation is correct or whether a change is required. After the FAT is completed, the machine is brought to the factory, "*Then they dismantle the entire machine and then a week later, two large heavy transports come here. And then it is placed here in production*. (CS)" (Table 9).

Stage 5. Full Production & Market Launch

In this stage the machine is placed in the production line by the supplier. In the factory a so-called Site Acceptance Test (SAT) is done. This test is performed to test the full production line, including the new machine, before it can proceed to full production. If a problem arises, the parties must meet again to discuss how the situation should be addressed. As an example "*The machine is then placed* *in the production line and the components of the tooling come in and you start testing them together. You will check whether these correspond to the predefined specifications. You then make test series.* (MET)" (Table 10). So-called 0-series are also produced here, "*We call this a 0-series when we do that for the first time. When the 0-series are ready, you have proven the quality with your test series. With a 0-series, an order goes into the system and a product comes from the factory* (MET)" (Table 10). When it appears that the 0-series has successfully been produced, full production is switched on.

The findings show that a project ends when the new products are in store, "*when the stores are equipped with the new product, we conclude that the project has come to its end.* (MET)" (Table 10). Another example is "*The main project is ready when we have established together that all prices are correct in the system and all times are correct in the system* (ME)" (Table 10) and "*we can formally close the project only six months after production has started, because then the numbers are made, then it goes into the market. Maybe something will come back from customers. Something you do not hope for. And if that is all good, then it is really ready* (EC1)" (Table 10).

Several respondents indicated that after entering full production, they will look at how the production process can be organized even more efficiently, "*Because what you also see is that we first go live and then we see additional potential for our production to be more efficient so that often comes after that* (ME)" (Table 10) and "*Because it is quite high tech that we make, it is usually the starting point and then some of our own Process Engineers tweak it. To be able to do it a little more precisely and to be able to do it a bit faster and to be able to do it better.* (MC)" (Table 10). A separate project for process innovations is not set up, "*It is not something that is reported on a weekly basis. These are more ongoing activities that take place in the background with us. It is something you spend serious time on, but you work less with hard deadlines nor well defined goals. You try to find a way to improve the machine.* (MC)" (Table 10). Respondents who have indicated that they want to implement process innovations for efficiency reasons, assign a team of production engineers and process engineers to this purpose. The respondents indicated that no new machines are being developed internally. The knowledge of production and process engineers is used to optimize processes with the help of new technologies. These technologies have been devised by external parties and possibly adapted to the processes within the company. The engineers determine the technical requirements for the new production process.

Post-Implementation Review

After the end of the project, evaluations also take place, "*You conclude a project with 'lessons learned' because you always want to be wiser about 'what went wrong?' and 'what went well?' and* *'what could be better?'. So that you can take it the next time in consideration* (EC1)" (Table 11). Another respondent indicated "*X-years later, of course, business control also looks back to see if the business case they had delivered corresponds to what they intended.* (ME)" (Table 11). Since production is part of new product development, production is also evaluated.

The findings in the modified Stage-Gate model are schematized in Figure 6.1.

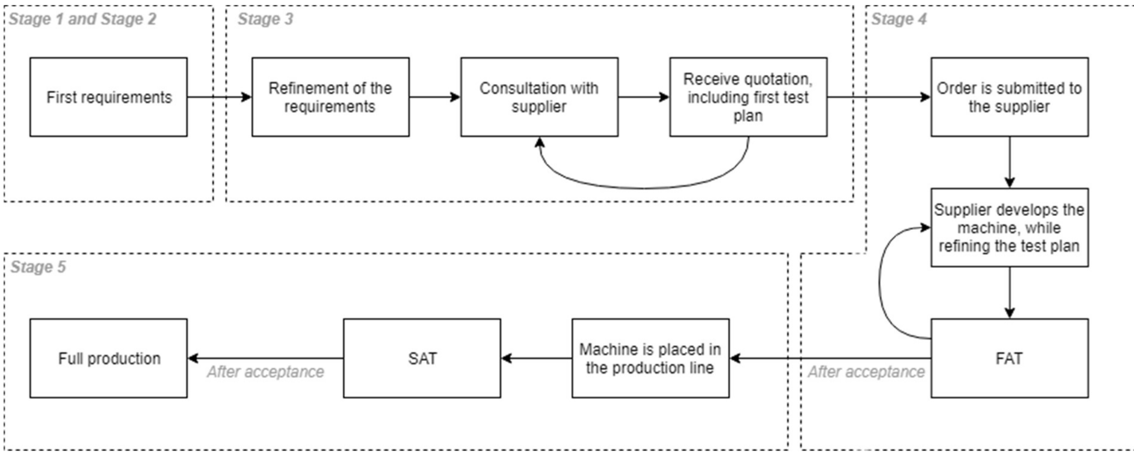

Figure 6.1. The modified Stage-Gate model for process innovations in SMEs

6.2.3 Learning strategies

This section deals with quotes about the learning strategies from Pisano (1997). The first part deals with *'Learning before doing'* (Table 12) and the second part with *'Learning by doing'* (Table 13).

The first part of this section focuses on findings about *'Learning before doing'*. One of the respondents indicated that they use simulation packages from external companies to get an impression of a new production line, "*that external party can set up a whole simulation and calculate the impact on assembly time, at test stations, etc.* (ME)" (Table 12). Another respondent indicated that he informs the supplier in advance what his wishes are for the new machine, "*at one point the representative has written three sheets full. He then notate all those wishes into a computer system. Such an entire machine is designed through that program.* (CS)" (Table 12). Another respondent also indicated that they outsource the design of the machine to the supplier, "*we draw the global concept of where the machines are located. We know about these machines that they have to glue at this point, turn over at that point and press something at another point. So we have a global idea of what the production line should look like. And for the machines you will already have conversations with the supplier. The supplier indicates whether he can make it and then the machine is completely drawn by him.* (MET)" (Table 12) These quotes point to the learning strategy '*Learning before doing*', whereby the machine is precisely designed in advance to ensure that the production line is renewed.

Concluding, the respondents indicated that they use computer simulations, but have them performed externally by the supplier. The simulations give the company an idea of how a new machine will look and how it will meet the requirements.

The second part of this section focuses on finding about *'Learning by doing'*. One of the respondents indicated that they would first start using the new production line and then adjust it, "*Because what you also see is that we first go live and then we see additional potential for our production to be more efficient so that often comes after that* (ME)" (Table 13). Another respondent also indicated that the production line would only be improved afterwards, "*Because it is quite high tech that we make, it is usually the starting point and then some of our own Process Engineers tweak it. To be able to do it a little more precisely and to be able to do it a bit faster and to be able to do it better.* (MC)" (Table 13). This also shows the experimental nature of adapting existing machines. In addition, another respondent also indicated that they would improve the production line after it was introduced. "*We can make them, but only in a few dozen. This is because there are still a number of teething problems in it. Now a large team focuses on eliminating those teething problems.* (EC1)" (Table 13). These quotes show that companies first choose to adjust a production line to ensure that the product innovation can be produced. Then it is examined how the production line can be set up more efficiently.

Concluding, these quotes point to the learning strategy *'Learning by doing'*, whereby adjustments were only made while the new production process was already in use.

To summarize the findings about the learning strategies -learning before doing versus learning by doing- the following can be stated. The quotes show that the companies use both learning strategies. They outsource the making of computer simulations to an external party (e.g. the supplier), which refers to *'Learning before doing'*. In addition, some respondents indicated that they would optimize the production line after it is introduced, which refers to *'Learning by doing'*. The use of these learning strategies ensures that process innovations can be successfully implemented.

6.2.4 Further findings

This section deals with findings that were gained in addition to the theory-guided coding.

Every requirement of the company regarding the new machinery needs to be tested. It was noticed that one respondent spoke specifically about the Factory Acceptance Test (FAT) and Site Acceptance Test (SAT), "*These are the FAT and the SAT. That is the acceptance test first in the factory and the second on the site, so at the company itself.* (MC)" (Table 14). It appears that tests are set up before delivery based on the requirements, "*You actually always agree in advance what you want to test. So, for example, do you want to do a general test? Or do you want to make a very specific customer product? Do you want to approve the machine after the production of one or after ten, after one hundred items?* (MC)" (Table 14). However, other respondents also talked about acceptance testing, only they did not specifically mention those terms. The findings did show that every requirement must be tested. The company sets the requirements and the supplier sets up the test, "*there are certain procedures for this that are agreed in advance with the supplier to test such a machine* (ME)" (Table 14). This is done through negotiations between the company and the supplier.

Concluding, requirements are drawn up in negotiations between the company and the supplier, resulting in a quotation that contains a test plan. Accepting the quotation, the company submits the order to the supplier. The supplier accepts the order to realize the innovation thereby also accepting the obligation to perform all planned tests, including a FAT and SAT. Both tests must be well completed before the company switch to full production.

R&D activities can also be carried out by non-R&D workers. Some of the respondents indicated that they did not have a specific R&D department in the company (CS, MC, EC2). Respondents did indicate that people were employed as production engineers and process engineers. These people often perform R&D activities that result in process innovations. An example is "*We do not officially have an R&D department. It's all a bit scattered. There are functions that only deal with R&D, but they are more like support staff at the workstations. So, for example, the part of the plant that cleans has an R&D Process Engineer. The part that deals with welding has a Process Engineer. You can see it that way.* (MC)" (Table 15). Another example "*One of the men at the paint shop has an R&D function. Together with another man from the paint shop, he was working internally to find a new solution for painting*. (CS)" (Table 15). Hence, the interviews show that several employees within the company are engaged in R&D activities. All respondents indicated that people from various departments are involved in development projects. It is not the case that only people who are specifically assigned to R&D within a company are involved in a product and process development project. So as a process progresses, other people are involved, depending on the stage of the project, "*But as you progress through the development process, people from other departments may be involved because you need more specific knowledge.* (ME)" (Table 15).

Concluding, several functionaries in the company are involved in process innovations, depending on the stage of the project. In SMEs the production workers and engineers of the production department also perform R&D activities.

6.2.5 Summary

The qualitative analysis was carried out to gain more insight into whether the knowledge needed to realize process innovations is being developed internally or externally and why it was decided to do certain activities internally and to outsource others to a third party. In addition, the development of process innovations has been mapped. The aforementioned relationships between the various concepts were investigated, for which six respondents were interviewed.

All respondents indicated that they mainly carry out R&D activities internally with regard to product innovations. The respondents did, however, seem to be in charge of designing the production line and managing the machinery themselves. It turned out that the respondents did have the knowledge to set technical requirements for the machine. However, most of the companies did develop the machines together with a supplier. The respondents did indicate that they were involved in the development of the machine, which means an open innovation approach, in which various ETA and ETE activities were observed during the interviews. However, it appeared that the respondents were not aware of the fact that they are engaged in open innovation. For them, it is more a matter of focusing on their core business, e.g., the product. In addition, all respondents have a similar approach in the realization of process innovations. This forms the basis of the modified Stage-Gate model that specifically describes the activities related to the development of process innovations.

6.3 Concluding words

Complementary to the quantitative analysis, a qualitative analysis was carried out in order to gain a more holistic view of creating knowledge (internal, external) and partnerships in the field of R&D, resulting in process innovations. By combining all results, it became clear which hypotheses can be supported in the quantitative analysis and which can be rejected. The quantitative analysis showed that both hypotheses were rejected. This would indicate that R&D partnerships do not have a positive impact on the realization of process innovations. However, the qualitative analysis has shown that these partnerships can lead to process innovations. After all, the respondents indicated that they have insufficient amount of knowledge to realize process innovation themselves. This is because they focus on their core business, e.g. the product. It is remarkable that the qualitative results shed a new light on the relationship between open innovation and process innovation, which thus indicates an moderating effect of external R&D on the relationship between internal R&D and process innovation. However, this relationship was not found in the quantitative analysis.

7 Summary, implications and limitations

In this chapter the conclusions, implications and limitations are discussed.

7.1 Summary

This thesis focusses on process innovation, referring to the implementation of technologies in production processes. Compared to product innovation, little research has been done regarding the development and implementation of process innovations, as the realization of process innovation depends on a development process. Further, it is still a challenge for companies to acquire knowledge to innovate their processes, whereby the effectiveness of the innovation approaches - open versus closed- is challenged. An open innovation approach refers to the combination of internal and external R&D activities, where an closed innovation approach refers to only internal R&D activities. Moreover, the internal R&D activities refer to R&D activities of a factory that are performed by own R&D personnel and external R&D activities refer to R&D activities that are carried out by external R&D personnel. After a brief introduction to the topics process innovation, internal R&D and open innovation, the following research question was formulated: *What is the influence of internal R&D and open innovation on the technological process innovation and its development process in the manufacturing industry?*

To answer this research question a mixed methods study was used that combines qualitative and quantitative research. The findings demonstrated mixed results. The quantitative results from the European Manufacturing Survey (2015) show that none of the relationships between the constructs examined are significant, implying that there is no direct effect between internal R&D and process innovation, nor is there a moderating effect of external R&D on the relationship between internal R&D and process innovation. Nevertheless, the outcome of the qualitative analysis provided additional findings that indicate why these effects were not found. The results demonstrate that internal R&D activities are not necessarily done by employees working in a R&D department. Some of the companies even did not have a R&D department. The findings suggest that process innovation is realized by multiple actors often dispersed in the organization.

Further, the qualitative analysis in this study demonstrates that open innovation (i.e. a combination between internal R&D and external R&D) is key in innovating processes. Specifically, internal R&D activities revolved around designing the production line and formulating requirements for new machinery. However to develop the machinery an external partnership, and thus R&D is required. Nevertheless, it should be noted that in order to have successful collaboration with external parties, and to ensure that the machinery designed externally meets the internal requirements a company’s internal R&D should be mature enough to ensure a sufficient tacit knowledge base. A tacit knowledge base refers specifically to all procedures, and processes that can have an influence on the success of the new production line. Hence, the findings of the qualitative analysis suggest that internal R&D and open innovation have a positive influence on the realization of process innovation.

In addition, the qualitative findings demonstrate that a modified version of the Stage-Gate model is applicable to the development of process innovation. Product innovation leads to process innovation and is therefore often developed simultaneously. For this reason it was decided to use the numbering of the stages of the original Stage-Gate model from Cooper (2008). In the modified model aimed at process innovations, the main purpose of the stages 1 and 2 is to formulate global requirements, whereby these requirements arise simultaneously with the requirements of the product. In stage 3, the requirements are refined and negotiations take place with suppliers, resulting in a quotation. The project enters stage 4 when the supplier accepts the order and starts the development. At the same time as the machine is developed, the supplier designs a test for each requirement. A Factory Acceptance Test (FAT) is conducted at the end of this stage. In Stage 5 a Site Acceptance Test (SAT) is performed. This often includes a test in which the entire production line is involved and for example a 0-series is produced. After the SAT has been approved, full production starts.

Moreover, this modified Stage-Gate model has been enriched by making use of the learning strategies of Pisano (1997). The findings indicate that companies simulate the future production line with the help of an external party prior to implementation, which corresponds to the learning strategy *'Learning before doing'*. After the process innovation has been implemented, the company starts optimizing the production line for reasons of efficiency, which corresponds to the learning strategy '*Learning by doing*'. Both learning strategies contribute to the successful implementation of process innovations.

Regarding the research question the following can be stated. The quantitative analyses could not endorse any relation between internal R&D and open innovation (i.e. a combination between internal R&D and external R&D) with process innovation. However, the findings of the qualitative analysis show that the realization of process innovations can be positively influenced by internal R&D and open innovation activities. Regarding the development process, it seems that improving a production line in SMEs usually concerns the purchase of new machinery. In SMEs, the development of these machines is outsourced, since they need to focus on their core business (i.e. the product) due to limited resources. This study explains that SMEs still can innovate effectively by using an open innovation approach. However, there should be more research in the activities that play a role in the development of process innovations. This is a research gap, given that this study demonstrated that additional activities are necessary to realize process innovations.

7.2 Implications

There are various theoretical and practical implications that arise from this study. First, the theoretical implications will be discussed and then the practical implications.

7.2.1 Theoretical implications

In this section the conclusions are mentioned that contribute to the existing literature.

Modified Stage-Gate model for process innovation. Compared to product innovation, little research has been done regarding the development and implementation of process innovations (Frishammar et al., 2012; Lager, 2010). Although it is important to separate product from process innovations (Tidd et al., 2005), this is not done in the literature concerning the development and implementation of process innovations. As a result, the same principles are applied to both types of innovation (e.g., Utterback, 1971). However, product and process innovation differ on various aspects (e.g. objective to innovate, competitive impact). Therefore, it cannot always be assumed that the insights gained through research focused on product innovations also apply to process innovation (Damanpour, 2010; Pisano & Shih, 2012). Each type of innovation can have its own development process by which an innovative idea is developed towards an actual final outcome being the innovation. Therefore, this thesis focusses on how process innovation is developed.

In the existing literature various stages in the development and implementations of process innovations are recognized. In each of these stages different activities take place and the necessary objectives are formulated (e.g., Kurkkio et al., 2011; Voss , 1992). These stages are also recognized by Hollen et al. (2013), whereby the development of process innovation is cut into several pieces. Ultimately, all of these stages can be found in the Stage-Gate model from Cooper (2008).

In addition, the qualitative findings demonstrate that a modified version of the Stage-Gate model is applicable to the development of process innovation. Product innovation leads to process innovation and is therefore often developed simultaneously. For this reason it was decided to use the numbering of the stages of the original Stage-Gate model from Cooper (2008).

In the modified model aimed at process innovations, stages 1 and 2 of the original Stage-Gate model can be combined because the main purpose here is to formulate global requirements, where stage 1 regards the global requirements. In stage 2 these requirements become slightly more specific and the project to develop the process innovation is formally started. These requirements arise simultaneously with the requirements of the product. In stage 3, the requirements are refined and negotiations take place with suppliers, resulting in a quotation that contains a list of all agreed requirements. The project enters stage 4 when the supplier accepts the order and starts the development. At the same time as the machine is developed, the supplier designs a test for each requirement. A Factory Acceptance Test (FAT) is conducted at the end of this stage. In Stage 5 a Site Acceptance Test (SAT) is performed, in which the entire production line is involved and for example a 0-series is produced. After the SAT has been approved, full production starts.

Moreover, this modified Stage-Gate model has been enriched by making use of the learning strategies of Pisano (1997), the findings indicated that companies will simulate the future production line with the help of an external party prior to implementation, which corresponds to the learning strategy *'Learning before doing'*. After the process innovation has been introduced for product innovation, the company starts optimizing the production line for reasons of efficiency, which corresponds to the learning strategy '*Learning by doing*'. Both learning strategies contribute to the successful implementation of process innovations.

The modified Stage-Gate model for process innovations in SMEs as formulated in this study contributes to the existing literature, because it makes a clear distinction between activities that focus on process innovation (Appendix VI).

By using an open innovation approach SMEs can realize process innovations. The existing literature showed that open innovation aimed on process innovations is relatively neglected (Huizingh, 2011; Un & Asakawa, 2015; West & Gallagher, 2006). It is unclear whether and to what extent external partners influence process innovations. Therefore, the effectiveness of open innovation to innovate processes is challenged (West & Gallagher, 2006), making them a topic of interest in this study, whereby open innovation is seen as a combination of internal R&D and external R&D (e.g., Chesbrough, 2003).

The quantitative results from the European Manufacturing Survey (2015) showed that the moderating effect of external R&D on the relationship between internal R&D and process innovation was not significant, implying that open innovation has no influence on process innovation. Nevertheless, the qualitative results from the interviews provide findings of R&D partnerships referring to open innovation, whereby companies realize process innovations with the help of an external party. A possible reason for the non-significant results from the quantitative analyses, may be that R&D activities are not necessarily done by employees working in the R&D department. Next to the fact that some SMEs even did not have a R&D department, the qualitative findings suggest that process innovations are realized by multiple actors in the company that perform R&D activities. In the qualitative analysis three open innovation practices formulated by Van de Vrande et al. (2009) can be identified by realizing process innovations, namely: involvement of non-R&D workers, outward licensing of intellectual property and R&D outsourcing.

This study has demonstrated that the involvement of non-R&D workers (i.e. the use of tacit knowledge) and R&D outsourcing are needed to realize process innovations for SMEs. These conclusions contributes to the existing literature about open innovation focusing on process innovation.

7.2.2 Practical implications

In this section the conclusions are mentioned that are applicable by the SMEs.

Management needs to investigate the tacit knowledge of their employees. This study emphasizes that a sufficient amount of knowledge is required within the company to realize successful process innovations. The qualitative analysis shows that companies often use the knowledge of non-R&D workers to realize process innovations. These employees possess tacit knowledge which is of great importance in the realization of process innovations. This knowledge can also be used to specialize more in process innovations. The qualitative analysis showed that SMEs are able to formulate requirements for the new production line, but that they always need the help of an external party to realize process innovations. A reason mentioned was that SMEs focus on their core business (i.e. the product) from a point of view of cost efficiency. In this way, they hope to avoid the risks of spending enormous amounts of time and money to develop the knowledge about process innovation themselves and losing sight of what they see as their true source of competitiveness: product research and development. However, Pisano and Wheelwright (1995) argue that this way of thinking can endanger the competitive position of a company. According to them, it is necessary to be an expert in product development and process development at the same time, because it can provide cost efficiency benefits. In markets where product technologies are being renewed quickly, the realization of process innovations is seen as an important capability for product innovation. A company that has structured its processes more efficiently than its competitors can thus gain a competitive advantage by distinguishing itself from others. This means that there is a challenge for companies to invest more (time and human) resources and attention to process R&D.

Concluding, a new world is opening up for SMEs in the field of process innovations. Therefore, the first recommendation is about the necessity that managers determine what knowledge is already present in their organization by also involving non-R&D workers in innovation projects regarding process innovations.

Collaboration with external parties contributes to the realization of process innovations. Open innovation is possible because companies can contact other organizations. An important implication of this study (qualitative analysis) is that R&D partnerships have a positive influence on the realization of process innovations. This study underlines the importance of participating in networks and visiting trade fairs in order to meet other companies with whom a cooperation can be started. Therefore, the second recommendation relates to the presence of R&D partnerships to realize process innovations. The qualitative findings in this study are in line with the open innovation approach (e.g., Chesbrough, 2003), whereby R&D partnerships with external parties will improve the development of new processes. Thus, in line with the open innovation literature, managers are advised to look beyond the boundaries of the organization and collaborate with suppliers to improve processes or introduce new ones.

7.3 Limitations and recommendations for future research

There are some limitations to the interpretation of the results and contributions of this research. The first limitation relates to the indicator that measures process innovation. It is recommended to include two additional questions in the EMS survey to measure it more accurately. In the quantitative analysis the amount of technologies in a company is used as an indicator of process innovation. There arises a question of the quality of this indicator. From the qualitative analysis the notion arose that SMEs improve their production line by purchasing new machines. However, the purchase of these machines does not necessarily mean that this also increases the number of technologies as supposed in the quantitative research. If, for example, an machine is replaced by a machine with automated input and output, in reality there is a process innovation. However, since the general type of the machine remained the same this innovation is not accounted by the indicator in the EMS (2015). Therefore it is recommended to add two questions regarding process innovation to the survey. The first question should identify the type of machine that is purchased and the second question has to focus on whether the new machine was innovative for the production process.

The second limitations relates to the indicator that measures internal R&D. From a theoretical point of view it is difficult to determine what it means that in the quantitative analysis there is no significant relation between internal R&D and process innovation. It could mean that internal R&D activities are not focused on process innovations and therefore have no influence on the realization of process innovations. It is more likely, however, that the question from the survey aimed to measure this concept provides an inadequate representation given that in many previous studies internal R&D has been related to process innovation. In this study, internal R&D was measured on the basis of the percentage of staff in a business location that is assigned to the R&D work area. However, referring to the qualitative findings in this study on tacit knowledge, for SMEs this percentage of staff underestimates the number of R&D activities. This implies that another indicator is needed to measure internal R&D efforts. Research shows that in other studies the extent of R&D (i.e. R&D intensity) was measured as '*R&D expenditures per employee*' (e.g. Mairesse & Mohnen, 2005) or '*R&D expenditures over total turnover*' (e.g. Medda, 2018). It is recommended to measure the constructs internal R&D and external R&D based on R&D expenditures.

The third limitations relates to the interviews. In this study six respondents were interviewed. This number of respondents is limited, which means that the generalizability of the answers can be questioned (e.g. Babbie, 2013). However, various respondents gave similar answers to the same questions from the interviews, which implies that the interviews give a clear impression of the Dutch manufacturing industry. In addition, the interviews were held in different industry sectors to obtain a balanced palette of respondents. This also contributes to the fact that this study provides a versatile impression of the development of process innovations in the Dutch manufacturing industry. Future research should conduct a larger number of interviews.

The fourth limitations relates to the correct use of definitions. It cannot be guaranteed that the interviewees have made a sufficient distinction between the meaning of the concept of process innovation and the concept of continuous process improvement. It is possible that when the interviewees spoke about innovations, they actually addressed improvements. Nevertheless, there is a substantial difference between continuous process improvement and process innovation (Elsevier, 2016). Continuous process improvement refers to the way things are done and refining or improving them (i.e. incremental process). This is about improving current processes. In comparison, the goal of process innovation is similar to that of continuous improvement, but the approach appears to be different. Process innovation involves major and disruptive changes (i.e. radical process). With the knowledge of these concepts, it can be questioned whether the respondents have used the same definition of process innovation.

The fifth relates to the country context. This study is based on a single country analysis. It is advisable to investigate process innovations in a different country context, to find out if process innovations are developed in a similar way.

With regard to the theoretical implications, the following recommendations can be made:

Modified Stage-Gate model for process innovation. In this study a modified Stage-Gate model for process innovation is presented, in which it is described for each stage which activities must be carried out to develop process innovations. Nonetheless, this modified Stage-Gate model will have to be refined. Various gates have been named in the original Stage-Gate model from Cooper (2008). However, not all gates have been named in the modified Stage-Gate model. It is important to add these gates because a gate is intended as a specific moment when management can decide on the progress of the project. At that point, the model still needs to be improved, whereby the gates have to be mapped even more specifically. The purpose of this is to create a global overview of how process innovations are developed in practice. Nevertheless, the modified model already gives a pretty clear impression, but is still a starting point in the direction of the development process of process innovation.

By using an open innovation approach SMEs can realize process innovations. In this study open innovation is only related to a combination of internal and external R&D. This is based on the definition that Chesbrough (2003) used in his study "*commercializing external (as well as internal) ideas by deploying outside (as well as in-house) pathways to market*" (p. 36). The focus is on conducting R&D within and outside the boundaries of the company, whereby "*external R&D can create significant value; internal R&D is needed to claim some portion of that value*" (Chesbrough, 2003; p. 38). However, the literature shows that open innovation is more than just the exchange of knowledge based on R&D activities. According to Chesbrough and Bogers (2014), open innovation is "*a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model*" (p. 12). The emphasis is more on partnerships between various parties (e.g. schools, institutes, competitors, consumers) that can contribute to the development of innovations, hence the focus is not on R&D. In this thesis, open innovation was measured in the quantitative analysis on the basis of the interaction effect between internal and external R&D. In future research, it is recommended to broaden the concept of open innovation by looking at which other sources (in addition to external R&D) must be approached by various actors in the organization in order to develop process innovations.

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Appendices

Appendix I

In this appendix the following can be found:

- Table 1: External Technology Acquisition (ETA) practices
- Table 2: External Technology Exploitation (ETE) practices

External Technology Acquisition (ETA)	
Practices	**Definition**
Customer involvement	Direct involvement of customers in innovation processes by actively conducting market research to monitor customer needs or by developing products based on specifications imposed by them or by producing products based on the design of the customer.
External networking	Collaboration between external partners (not customers) to support innovation processes, whereby specific knowledge needs can be met quickly without spending enormous amounts of time and money to develop this knowledge themselves. Maintaining connections with external sources plays hereby an important role.
External participation	Equity investments in start-ups or other businesses to gain access to their knowledge or to create other synergies.
Outsourcing R&D	Outsourcing R&D activities to other organizations to acquire external knowledge which can be bought or licensed.
Inward licensing of IP	Externally acquiring intellectual property (patents, copyrights or trademarks) from other organizations to take advantage of external innovation opportunities.

Table 1. External Technology Acquisition practices (Van de Vrande et al., 2009)

External Technology Exploitation (ETE)	
Practices	**Definition**
Venturing	Starting up new organizations based on internally generated knowledge. The parent company can offer support for the spin-off through, among other things, finance and human capital.
Outward licensing of intellectual property (IP)	Companies can better benefit from their own intellectual property by letting other companies with different business models make use of it by selling or offering licenses/patents to them.
Involvement of non-R&D workers	Utilizing the knowledge and initiatives of current employees, including employees who are not employed by the R&D department, to realize innovations.

Table 2. External Technology Exploitation practices (Van de Vrande et al., 2009)

Appendix II

In this appendix the interview script can be found.

Interview Script	
Intro (5 minuten)	Als eerst wil ik u graag bedanken dat u tijd heeft vrijmaakt voor dit interview. Mijn naam is Marijn Bouvy en ik ben een student van de Radboud Universiteit. Ik doe een onderzoek naar de invloed van interne R&D en open innovatie op technologische procesinnovaties en naar de ontwikkeling van deze technologische procesinnovaties. In dit onderzoek focus ik mij op middel-kleinbedrijven die opereren in de maakindustrie. Het interview zal ongeveer een uur duren. Vindt u het goed als ik het interview opneem? De informatie die uit de interview naar voren komt, zal alleen voor dit onderzoek worden gebruikt en de opname zal achteraf vernietigd worden. De antwoorden zullen anoniem worden gemaakt om uw privacy te waarborgen. Het interview transcript zal ter validatie naar u worden gestuurd. Heeft u wellicht al vragen vooraf?
1. Oriënterende vragen (5 minuten)	**a. Wie bent u en wat is uw rol binnen het bedrijf?** (functie, ervaring algemeen, binnen bedrijf, hoe lang werkzaam voor bedrijf?) **b. Bij wat voor soort bedrijf werkt u ?** (bedrijfsvestiging zelfstandige onderneming? Aantal werknemers vestiging? Bedrijfstak (bijv. machinebouw?) Hoofdproduct(en)?) **c. Op welke manieren bent u betrokken bij innovatie activiteiten in uw bedrijf ?** (productie? productontwikkeling? Innovatiestrategie? Focus op werkzaamheden/ activiteiten)
2. Technologische procesinnovatie (TPI) (10 minuten)	Zoals ik al eerder heb genoemd, richt ik mijn onderzoek op technologische procesinnovaties. Hierbij kijk ik hoe bedrijven nieuwe technologieën ontwikkelen en implementeren in hun productieprocessen, wat resulteert in een verbeterd productieproces. Ik ben benieuwd in hoeverre uw bedrijf zich bezighoudt met technologische procesinnovaties. Om deze reden wil ik u enkele vragen daarover stellen.

	a. Welke vernieuwingen/ verbeteringen zijn er in de afgelopen tijd doorgevoerd in de productie (bijv. machines, installaties, gereedschappen) in uw bedrijf? (Welke technologieën/systemen? Soort machine? Robot/freesmachine/productiesysteem/digitaal/duurzaam?) **b. Wat vormt vooral aanleiding tot het invoeren van deze veranderingen (innovatie-impulsen/ideeën)?** (Intern: R&D, productieafdeling, klantenservice, leiding bedrijfsvestiging?), (Extern: klant/gebruiker, leverancier, onderzoeksinstellingen/universiteiten, conferenties/beurzen?) Voorbeelden? **c. Met welk doelen voert uw bedrijf voornamelijk technologische procesinnovaties uit? Wat is het voornaamste doel?** Efficiëntie, t.b.v. product(innovatie) **d. Hoe komen deze innovaties in de productie tot stand?** (eigen R&D? Welke functies/afdelingen zijn op welke manier bij betrokken? Externe partijen?
3. Ontwikkeling van TPI (15 minuten)	Ik heb nu een beeld gekregen in hoeverre uw bedrijf zich bezighoudt met technologische procesinnovaties. Ik zou nu graag wat meer willen weten over hoe de ontwikkeling van technologische procesinnovaties in uw bedrijf verloopt, via welke stappen etc. (Focus op laatste omvangrijke project) **a. Kunt u in het algemeen vertellen hoe het ontwikkelingsproces verloopt?** (welke stappen, beslismomenten (wie, wanneer) herkent u hierin... **b. Hoe komt uw bedrijf op ideeën voor technologische procesinnovatie? Hoe vindt het screenen van ideeën plaats?** (Door wie/afdeling wordt dit gedaan?)

	c. Hoe worden technische vereisten bepaald voor het project? Hoe worden deze vereisten beoordeeld/gescreend? **d. In hoeverre wordt er gedurende het project een proces/productdefinitie gecreëerd en een gedetailleerd projectplan gemaakt? Hoe wordt beoordeeld of het project wordt voortgezet om een prototype te maken?** **e. Door wie/welke afdeling wordt het prototype gemaakt en wordt deze intern getest of ergens anders? Hoe wordt beoordeeld of het project verder mag worden voortgezet om daadwerkelijke getest te worden en de levensvatbaarheid van het project te bepalen?** **f. Hoe vindt het testen en valideren van de volledige levensvatbaarheid van het project plaats? Hoe wordt bepaald of het project mag worden voortgezet naar de implementatiefase?** **g. Hoe wordt de technologie ingevoerd in het productieproces?** Implementatie: (gedeelte) productie stil gelegd? Hoe worden mensen ingelicht? **h. In hoeverre wordt het project en de prestaties van het proces geëvalueerd? Vanaf welk moment is het project beëindigd?** **Aanvullend:** *Maakt uw bedrijf gebruik van bijvoorbeeld (computer)simulaties om een innovatie te ontwikkelen m.b.t. het productieproces? (learning before doing)(praktijkvoorbeelden) Of heeft u meer de voorkeur om een innovatie te implementeren in het productieproces en naderhand aan te passen? (learning by doing) Of maakt uw bedrijf van beide strategieën gebruik, een balans?*
4. Interne R&D (5 min)	Ik ben benieuwd in welke mate en welke activiteiten u op het gebied van interne R&D uitvoert in uw bedrijf? **a. Welke activiteiten worden er bij uw bedrijf uitgevoerd inzake interne R&D?**

	b. Wat betekent interne R&D voor uw bedrijf? (Welke functies/ afdelingen zijn op welke manier hierbij betrokken zoals *niet-R&D werknemers*?) **c. Stelt u uw kennis ook beschikbaar aan externe partijen?** (*verkopen IP, spinoffs*?)
5. Externe R&D (5 minuten)	Ik ben benieuwd in welke mate en welke activiteiten u op het gebied van R&D uitbesteed? **a. Welke R&D activiteiten worden er bij uw bedrijf uitgevoerd door externe partijen?** Geen interne R&D bij betrokken? Waarom voert u deze activiteiten niet intern uit? **b. Op welke manieren beïnvloedt Externe R&D de vernieuwingen in de productie (bijv. machines, installaties, gereedschappen)?** (voorbeelden, activiteiten, ondersteuning, hindernissen, risico's)?
6. Open innovatie (5 minuten)	Het idee van open innovatie is dat bedrijven niet langer volledig afhankelijk kunnen zijn van eigen innovatie, door uiteenlopende ontwikkelingen (mobiliteit van werknemers, scholing, externe kennis en toegankelijkheid) en dus op zoek gaan naar samenwerkingen in diverse vormen? **a. In welke mate heeft uw organisatie samenwerkingsverbanden op het gebied van R&D?** (kennis van, concrete plannen, beslissingen, implementeren, monitoren, resultaten, effecten) b. **Met welke partijen werkt u voornamelijk samen om technologische procesinnovatie te kunnen realiseren? En in welke mate? Hoe komt u aan nieuwe kennis voor deze innovaties?** (Leveranciers, concurrenten, consumenten, universiteiten? Bezoeken van beurzen of aan nieuwe kennis te komen?)
Outro	Dan zijn we op het einde gekomen van dit interview. Heeft u verder nog aanvullingen voor dit interview? Ik wil u nogmaals bedanken voor de tijd

	die u heeft vrijgemaakt voor dit interview. Ik zal het transcript van dit interview voor goedkeuring naar u sturen en uw informatie anoniem in mijn onderzoek gebruiken. Zodra het gehele onderzoek afgerond is kan ik het u digitaal toesturen als u daar interesse in heeft?

Appendix III

In this appendix the operationalization from the items used from the European Manufacturing Survey (2015) can be found.

Operationalization: items used from EMS (2015)		
Type variable	Construct	Items used from European Manufacturing Survey (2015)
DV	Technological Process Innovation	*Question 8.1 Welke van de volgende technologieën worden momenteel in uw bedrijfsvestiging toegepast?* - Industriële robots voor bewerking en fabricage - Industriële robots voor hanteren van gereedschap en werkstukken in productie - Controlesystemen die machines stilleggen bij onderbenutting - Geautomatiseerde beheerssystemen voor energie efficiëntie productie - Systemen t.b.v. terugwinning van kinetische en procesenergie - Productietechnologieën voor micromechanische componenten - Nanotechnologische productieprocessen - Technieken voor verwerking in composietmaterialen - Bio- en gentechnologie in fabricageprocessen - Technieken voor verwerking van legeringen - Digitale productieplanning en roostering - Bijna real-time productiebeheersingssystemen - Digitale uitwisseling van productieplanningsgegevens met toeleveranciers en/of klanten - Systemen voor geautomatiseerde management van interne logistiek en orderverzameling - Mobiele/draadloze apparaten voor programmering en bediening van installaties en machines - Product Lifecycle Management (PLM) systemen of Product/Productieproces datamanagement - Technologieën voor veilige mens-machine interactie - Digitale oplossingen voor het direct beschikbaar maken van tekeningen, werkschema's en –instructies op de werkvloer

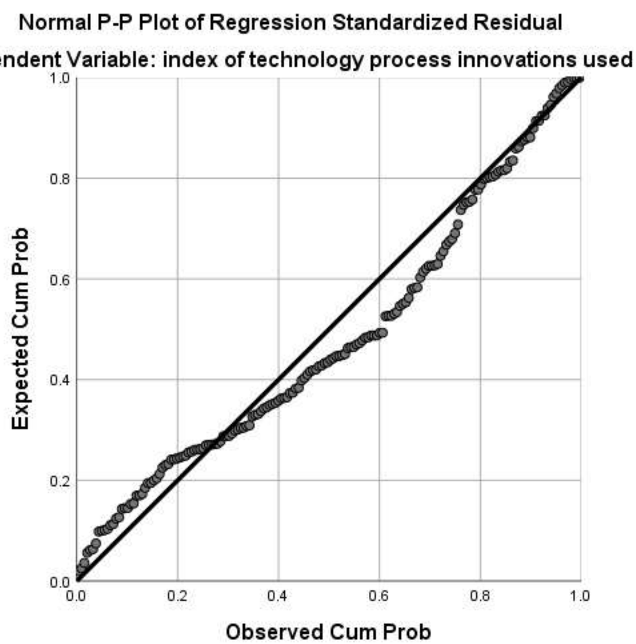
IV	Internal R&D	*Question 15.2: Hoe is het personeel in uw bedrijfsvestiging verdeeld over de volgende werkterreinen?*
IV	External R&D	*Question 1.5: In hoeverre voert uw bedrijfsvestiging voor het hoofdproduct de volgende activiteiten uit van het waardecreatieproces?*
CV	Firm Size	*Question 21: Aantal werknemers in 2014?*
CV	Industry	*Question 1.2: Bedrijfstak (bijv. textiel, chemische industrie, machinebouw, enz.)*

Appendix IV

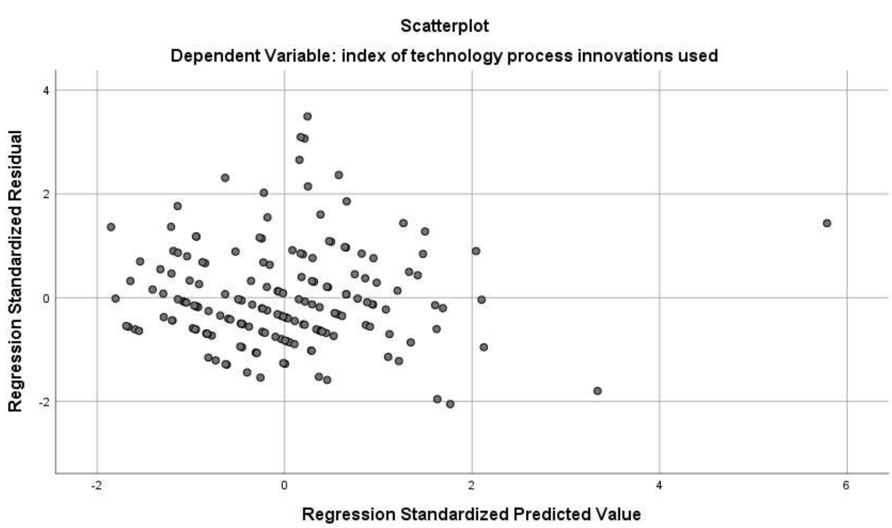
In this appendix the following can be found:

- Linearity - *scatterplot*
- Homoscedastic – *scatterplot*
- Table: Residual statistics
- Table: Reliability Statistics construct Technological Process Innovation
- Table: Item-Total Statistics construct Technological Process Innovation
- Correlation matrix

Linearity



Homoscedastic



Independence of the error terms: Residual statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.963	12.801	3.833	1.550	174
Residual	-4.572	7.788	.000	2.157	174
Std. Precticed value	-1.852	5.786	.000	1.000	174
Std. Predicted value	-2.052	3.495	.000	.968	174

Reliability Statistics construct Technological Process Innovation

	Cronbach's Alpha	Conbach's Alpha Based on Standardized Items	N of Items
	.681	.695	18

Item-Total Statistics construct Technological Process Innovation (N- = 177)

Items	Mean	Std. Deviation
Industriële robots voor bewerking en fabricage	.3616	.48182
Industriële robots voor hanteren van gereedschap en werkstukken in productie	.2373	.42663
Digitale productieplanning en roostering	.7401	.43982
Bijna real-time productiebeheersingssystemen	.3446	.47660
Digitale uitwisseling van productieplanningsgegevens met toeleveranciers en/of klanten	.3277	.47070
Systemen voor geautomatiseerde management van interne logistiek en orderverzameling	.2655	.44287
Mobiele/draadloze apparaten voor programmering en bediening van installaties en machines	.1525	.36057
Product Lifecycle Management (PLM) systemen of Product/Productieproces datamanagement	.1525	.36057
Technologieën voor veilige mens-machine interactie	.1130	.31748
Digitale oplossingen voor het direct beschikbaar maken van tekeningen, werkschema's en –instructies op de werkvloer	.3559	.48015
Controlesystemen die machines stilleggen bij onderbenutting	.0621	.24211
Geautomatiseerde beheerssystemen voor energie efficiëntie productie	.0904	.28756
Systemen t.b.v. terugwinning van kinetische en procesenergie	.2316	.28756
Productietechnologieën voor micromechanische componenten	.0395	.19545
Nanotechnologische productieprocessen	.0621	.24211
Technieken voor verwerking in composietmaterialen	.0904	.28756
Bio- en gentechnologie in fabricageprocessen	.0113	.10600
Technieken voor verwerking van legeringen	.1751	.38117

Correlation matrix (N = 174)

Variable	1	2	3	4	5	6	7	8	9	10	11
Technological Process Innovation	1.000										
lnSize number of employees	.554***	1.000									
Food	-.007	.066	1.000								
Textile	-.120	-.030	-.129*	1.000							
Construction	.059	.086	-.097	-.108	1.000						
Chemical	-.061	.033	-.129*	-.145*	-.108	1.000					
Machinery	.137*	.116	-.158*	-.177**	-.132*	-.177**	1.000				
Electronic	.041	-.120	-.158*	-.177**	-.132*	-.177**	-.217**	1.000			
R&D active	.040	.028	.133*	-.0556	.111	-.005	-.084	.004	1.000		
Internal R&D	-.008	-.040	-.070	-.051	-.046	.006	.002	.207**	.306***	1.000	
External R&D	.041	-.004	.084	-.050	.028	-.027	-.147	.007	.406***	-.086	1.000

Note. The metal industry is the reference category for industry.

**p<.05, **p<.01, ***p<.001*

Appendix V

In this appendix the following can be found:

- Table regarding subjects theoretical coding
- Table regarding the ID codes referring to the respondents interviewed
- Tables (1-14) with Dutch quotes arranged per subject. The English translation of the quotes can be found in chapter 6.2 (sections: 6.2.1 – 6.2.4).

Subjects theoretical coding	
Subjects:	Cooperation
	Development process
	Efficiency
	External R&D activities
	Improvements
	Internal R&D activities
	Machines
	Open innovation activities
	Process innovation
	Product innovation
	Production line
	Project
	Purpose
	R&D functionaries
	R&D partnerships
	Reason
	Stages: Idea generation Development Testing Implementation Full production Evaluation

The ID codes referring to the respondents	
ID	*Industry sector*
ME	Metal
CS	Construction furniture
EC1	Electrical equipment
MET	Metal/Electrical/Textile
EC2	Electrical equipment
MC	Machinery

Table 1 *Quotes regarding the purpose of implementing process innovations*	
ME	als wij een nieuwe productinnovatie hebben, dus een opvolger van ketel A naar ketel A+, dan kan het zijn dat een aantal handelingen veranderen aan assemblage. Dus je moet gaan kijken naar je handelingen. Dat kan betekenen dat je een zaak heel anders aan gaat pakken.
ME	welke handelingen zijn veel repeterend? Welke handelingen zijn ergonomisch niet verantwoord? We hebben namelijk best wel zware producten. Kan je daar niet toepassingen bij gebruiken?
MET	Hier gaan we een productielijn ontwikkelen voor circulaire matrassen. Wij gaan al onze matrassen vervangen door circulaire matrassen. Dat is een nieuw productieproces die nog niet bestaat.
EC1	je richt je meer op hoe je het proces kan finetunen. Dan moet je je helemaal focussen en timen met een stopwatch. Je pakt een item op en je legt het weer neer, je gaat ermee schuiven. In het geval dat mensen moeten gaan puzzelen, duurt een productiestap zomaar 4 of 5 seconden langer. Zijn er simpele tools nodig zodat mensen niet hoeven te denken?
ME	Want wat je ook ziet, is dat we eerst live gaan en daarna zien we extra potentie om onze productie efficiënter in te richten. Dus dat komt vaak daarna.

Table 2 *Quotes on internal R&D activities*	
MET	De hele lijn tekenen wij, dus wij bewaken het hele machinepark. Maar dedicated machines worden door leveranciers gedaan.
EC1	Wij hebben productie engineers die productielijnen maken. Bij het maken van een productielijn, is wel meer kennis nodig vergeleken met de productiemedewerkers die alleen producten assembleert.
MC	Wij beschikken ook wel over de kennis van hoe de machine precies werkt
CS	Ik heb in machinefabrieken gewerkt dus ik weet technisch gezien hoe een frequentieomvormer en elektronica werkt. Ik weet hoe de machines worden aangestuurd en door welke machines en applicaties.

Table 3 *Quotes about why companies chose to enter into partnerships in the field of R&D*	
EC1	op het moment dat je een machine moet gaan ontwikkelen die in jouw productielijn komt, dan dwaal je van je core business af.
ME	Wij groeien als bedrijf zo hard, dat we wel bepaalde R&D activiteiten moesten uitbesteden. Hierdoor konden wij ons meer focussen op onze taken. Daardoor zijn wij nu alleen nog maar gefocust op het doen waar we goed in zijn, het ontwikkelen van nieuwe ketels.
CS	Wij hebben ervoor gekozen om het extern te laten ontwikkelen omdat wij hier niet de goede middelen hebben om dat zelf te doen.
MC	Sommige dingen liggen buiten je eigen competentie. Stel je hebt bepaalde sensoren nodig waarmee je het proces beter kan laten verlopen. Nou elektronica is niet ons ding dus dat besteden we dan uit. Het is ook gewoon goedkoper om het uit te besteden.

Table 4 *Quotes on open innovation activities - process*	
EC1	Er wordt ook kennis van productiemedewerkers gebruikt, want wij kunnen wel denken dat het allemaal makkelijk is, maar soms zit er net een of ander knikje in het productieproces.
MET	Bij het maken van een prototype worden zoveel mogelijk mensen betrokken die uiteindelijk ook het product gaan maken. Op deze manier kun je ook hun opmerkingen nog meenemen in de ontwikkeling.
MET	Wij moeten zorgen dat onze concurrenten ook deze matrassen gaan verkopen zodat volumes omlaag gaan en kostprijs ook en dan zijn we competitief. Dus concurrenten hebben wij nodig. Wij zijn nu actief onze concurrenten aan het bezoeken om te vragen of zij niet ook deze matrassen willen leveren. Wij staan open voor concurrenten die de door ons ontwikkelde productielijn willen namaken.
MET	De hele lijn tekenen wij, dus wij bewaken het hele machinepark. Maar dedicated machines worden door leveranciers gedaan.
EC1	In het geval dat een volledig nieuwe productiestap in een productielijn moet worden opgenomen, een stap waarvan de productie-ingenieurs onvoldoende

	kennis hebben, probeer je een oplossing op de markt te vinden. Dan gaan we op zoek naar een partner die ons daarbij kan helpen.

Table 5 *Quotes regarding Stage 0.*	
EC1	De eindgebruikers geven een bepaalde specificatie van wat ze willen. We zullen dan iets maken dat aan die specificaties voldoet.
ME (Metal)	Nederland wordt momenteel gedomineerd door 'minder gas', wat gebaseerd is op het overheidsbeleid. Maar dat heeft natuurlijk ook invloed op ons bedrijf. Dit betekent dat we hier ook een innovatieafdeling voor hebben die samen met onze zusterbedrijven over dergelijke zaken nadenkt
MET	Maar met name worden we bij de standaard branche beurzen niet zo veel verrast, dus bezoeken we veel beurzen uit andere sectoren. Bijvoorbeeld wintersportbeurzen of architectenbeurzen waar we nieuwe materialen voor onze producten kunnen ontdekken. Naar mijn mening worden in een sector altijd zeer kleine stappen gezet. Maar als je technieken uit een andere sector in je eigen sector gaat toepassen, kun je plots een heel grote stap zetten.
MET	het is iets meer vrijblijvend, een creatief proces

Table 6 *Quotes regarding Stage 1.*	
MET	omdat je anders niet kunt inschatten wat de kostprijs zou kunnen zijn. Maar in de propositiefase is het wel een zeer ruwe schatting.
MET	De propositie fase, als je die oplevert, dan heb je alles scherp om een projectbrief te schrijven.
MET	Dat is een product manager in de meeste gevallen en een propositie designer. Die twee gaan eigenlijk hand in hand dit uitwerken. Zij betrekken zelf wel disciplines, maar het is niet echt een projectteam die elke week bij elkaar komt met een pull-bord en een planning bewaakt.
EC1	nou dan moet de projectleider het presenteren en dan bepaalt MT of hij in die gate door mag. Dat is dan een echte 'go' of een 'no go' om de volgende fase te starten

MET	en dan na de propositie gate dan gaat zo’n project echt aan. Dan krijgt het status in de organisatie. En dan is het projectteam echt in de lead. Maar dit echt de gate dat MT zegt ‘die propositie is inderdaad interessant en die gaan we doen of we doen ‘m niet.

Table 7 *Quotes regarding Stage 2.*	
MET	In de conceptfase heb je eigenlijk alle moeilijke beslissingen gemaakt. Dan is je kostprijs ook grotendeels bepaald, omdat je je techniek, productieproces in concept al allemaal hebt bedacht.
MET	we hebben drie mogelijke invullingen van techniek voor het product en dit is de beste. Dat beslist de MT niet, want dat beslist het projectteam. Als het maar binnen de projectbrief valt.
MET	Hier staat een lijmmachine die moet werken met een lijm die we samen met een toeleverancier hebben ontwikkeld. Deze machine moeten we zelf ombouwen en testen. De resultaten dienen als proof of concept. Pas hierna kunnen we met een leverancier overleggen wat voor een machine wij daarvoor nodig hebben.
MET	Al je leverancierskeuzes zijn in de conceptfase al bedacht
EC1	is het potentieel goed, is de marktprijs goed, is de kostprijs goed? Zo ja, dan kunnen we door
EC1	het hangt ervan af in welk stadium het hele project zich bevindt, welk deel van het projectteam samenkomt. En geleidelijk kunnen derden een keer langskomen. Maar dus in een vroeg stadium is er een heel team

Table 8 *Quotes regarding Stage 3.*	
EC1	Nou dat gaat houtje touwtje. Het is gewoon losjes in elkaar gezet en je wil er verzekerd van zijn dat het werkt. Dat het er helemaal niet mooi uitziet, doet er niet toe.
EC1	in dat vroege stadium is het bedrijf zelf instaat om dat nieuwe product te ontrafelen, zodat productie-ingenieurs die verschillende productiestappen goed kunnen definiëren

EC1	de meeste bedrijven denken eerst functioneel, maar in een vroeg stadium moet je al nadenken over hoe je het kunt maken en welke productiestappen erbij betrokken zijn
ME	wij hebben een bepaalde volgordelijkheid van produceren in ons productieproces.
ME	de productie wordt erbij betrokken en er wordt gekeken naar de produceerbaarheid van het product.
ME	er moet al een heel duidelijk beeld zijn van hoe de nieuwe productielijn eruit zal zien. Maar ook als we de huidige productielijn moeten aanpassen, wat moeten we dan aanpassen?
EC1	In het geval dat een volledig nieuwe productiestap in een productielijn moet worden opgenomen, een stap waarvan de productie-ingenieurs onvoldoende kennis hebben, probeer je een oplossing op de markt te vinden. Dan gaan we op zoek naar een partner die ons daarbij kan helpen.
MET	als je weet dat iemand anders het ook kan, dan vergelijk je de aangeboden prijzen en oplossingen
CS	als het door de leverancier geleverde product zodanig goed is en ik kan het inpassen in mijn productiesysteem, dan heeft deze leverancier ook best kans dat de vervolgmachines straks ook uit zijn straatje komen.
CS	Ook voor je bedienaars in je organisatie is het natuurlijk hartstikke fijn dat je met één systeem werkt.
EC1	Maar kunnen ze ook service verlenen? Kunnen ze ook voor onderhoud zorgen? Je moet met al deze aspecten rekening houden, omdat je het onderhoud niet zelf kunt doen omdat het allemaal nieuw voor je is.
CS	Zo’n zaag kopen, is niet iets wat je even op een maandagochtend doet. Het is wel een proces van 2, 3 á 4 weken intensief qua uren.
MET	Aan het eind van de ontwikkelfase heb je al je tekeningen definitief, al je offertes definitief voor gereedschappen en dergelijke. Dan zeg je: dit is het point of no return . Als we nu gaan, dan gaan we alle investeringen doen. Als we dus ‘ja’ zeggen dan worden de investeringen gedaan en dan ga je naar de realisatiefase.

EC1	Je hebt een bepaald punt van ‘no return’. Dat is vaak als er al samples zijn en de eerste testen zijn gedaan en wij geloven dat het een veelbelovend product is.
MC	Je komt eigenlijk altijd van tevoren overeen wat je wilt testen. Dus wil je bijvoorbeeld een algemene test doen? Of wil je een heel specifiek klantproduct maken? Wilt u de machine goedkeuren na de productie van één of na tien, na honderd items?
MC	Het wordt meestal gedragen door een technisch persoon en dat wordt dan ondersteund door bijvoorbeeld inkopers of mensen van de planning omdat zij alle inputs krijgen over aan welke eisen het moet voldoen.
MET	Het is vaak de inkoper, een gereedschap projectleider, een productontwikkelaar van het team en de leverancier die waar waarborgen dat de machine alles kan om elk product te kunnen maken.

Table 9 *Quotes regarding Stage 4.*	
ME	het prettige daarvan is, is dat je ook de mensen die uiteindelijk dat product moeten assembleren, erbij gaat betrekken. En wat we vaak onderschatten, misschien nog steeds wel, is de kennis die daar aanwezig is.
EC1	Er wordt ook kennis van productiemedewerkers gebruikt, want wij kunnen wel denken dat het allemaal makkelijk is, maar soms zit er net een of ander knikje in het productieproces.
CS	Ik neem wel eens een werknemer van productie mee.
CS	Als de leverancier aangeeft dat de machine klaar is, dan ga ik de fabriek bezoeken. De machine staat daar dan helemaal opgesteld en in werking gesteld. Dan ga ik daar een hele dag planken zagen.
CS	Ik controleer of de machine aan alle eisen voldoet. Op het moment dat ik ervan overtuigd ben dat dat het geval is, dan zet ik een handtekening.
CS	Dan gaan zij de hele machine demonteren en dan een week later, komt hier twee grote zware transporten. En dan wordt die hier in de productie geplaatst.

Table 10 *Quotes regarding Stage 5.*	
ME	Dus de productie is dan gewoon niet gepland.
MC	het meest voorkomende is om het gewoon ergens anders te bouwen en het alleen af te breken als je zeker weet dat het werkt
MET	Vervolgens wordt de machine in de productielijn geplaatst en komen de componenten van de tooling binnen en begin je deze samen te testen. Je gaat controleren of deze overeenkomen met de vooraf opgestelde specificaties. Je maakt dan testseries.
MET	Dan komt het product uit die fabriek. We noemen dit een 0-serie wanneer we dat voor het eerst doen. Wanneer de 0-serie klaar is, heb je de kwaliteit bewezen met je testreeks. Met een 0-serie gaat een bestelling in het systeem en komt er een product uit de fabriek.
MET	wanneer de winkels zijn uitgerust met het nieuwe product, concluderen we dat het project is afgelopen.
ME	Het hoofdproject is klaar als wij met elkaar hebben vastgesteld dat alle prijzen juist staan in het systeem en alle tijden juist staan in het systeem.
EC1	we kunnen het project pas formeel na zes maanden afsluiten nadat de productie is gestart, want dan worden de cijfers gemaakt en gaat het de markt op. Misschien komt er iets van klanten terug. Iets waar je niet op hoopt. En als dat allemaal goed is, dan is het echt klaar
ME	Want wat je ook ziet, is dat we eerst live gaan en daarna zien we extra potentie om onze productie efficiënter in te richten. Dus dat komt vaak daarna.
MC	Omdat het vrij high-tech is die we maken, is het meestal het startpunt en dan passen sommige van onze eigen Process Engineers het aan. Om het iets nauwkeuriger te kunnen doen en het iets sneller te kunnen doen en het beter te kunnen doen
MC	Het is niet iets dat wekelijks wordt gerapporteerd. Dit zijn meer doorlopende activiteiten die bij ons op de achtergrond plaatsvinden. Het is iets waar je serieus tijd aan besteedt, maar je werkt minder met harde deadlines en harde doelen. Je probeert een manier te vinden om de machine te verbeteren.

Table 11 *Quotes regarding Post-Implementation review.*	
EC1	Je sluit een project af met 'geleerde lessen' omdat je altijd wijzer wil worden over 'wat is er misgegaan?' en 'wat ging goed?' en 'wat is er beter?'. Zodat je het de volgende keer in overweging kunt nemen
ME	X-jaren later, kijkt business control natuurlijk ook terug of de business case die ze hadden opgeleverd overeenkomt met wat ze van plan waren.

Table 12 *Quotes regarding 'Learning before doing'.*	
ME	die externe partij kan een hele simulatie opzetten en berekenen wat de impact is op assemblagetijd, op teststations et cetera.
CS	op een gegeven moment heeft de vertegenwoordiger drie blaadjes vol geschreven. Dan gaat hij daarmee naar huis en daar heeft hij een computersysteem waar hij al die wensen intikt. Via dat programma wordt zo'n hele machine ontworpen.
MET	wij tekenen het globale concept van waar de machines staan. Van die machines weten we dat ze op dit punt moeten lijmen, daar moet je iets omkeren en daar moet iets geperst worden Het gaat hier om het idee. En voor de machines ga je al gesprekken met de leverancier hebben. De leverancier geeft aan of het lukt en vervolgens wordt de machine door hen helemaal uitgetekend.

Table 13 *Quotes regarding 'Learning by doing'.*	
ME	Want wat je ook ziet, is dat we eerst live gaan en daarna zien we extra potentie om onze productie efficiënter in te richten. Dus dat komt vaak daarna.
MC	Omdat het vrij high-tech is die we maken, is het meestal het startpunt en dan passen sommige van onze eigen Process Engineers het aan. Om het iets nauwkeuriger te kunnen doen en het iets sneller te kunnen doen en het beter te kunnen doen

EC1	We kunnen ze maken maar alleen nog in enkele tientallen. Dit komt omdat er nog een aantal kinderziektes in zitten. Nu zit er een groot team op om die kinderziektes eruit te halen.

Table 14 *Further findings - Testing.*	
MC	daar zijn bepaalde procedures voor die van te voren ook met de leverancier worden afgesproken om zo'n machine te testen.
MC	Dat zijn de FAT en de SAT. Dat is dus de acceptatietest eerst in de fabriek en de tweede on 'the site', dus bij het bedrijf zelf.
MC	Je komt eigenlijk altijd van tevoren overeen wat je wilt testen. Dus wil je bijvoorbeeld een algemene test doen? Of wil je een heel specifiek klantproduct maken? Wilt u de machine goedkeuren na de productie van één of na tien, na honderd items?

Table 15 *Further findings - R&D functionaries*	
MC	Wij hebben niet officieel een R&D afdeling. Het zit allemaal wat verspreid. Er zijn wel functies die zich alleen maar bezighouden met R&D, maar die zitten meer als ondersteunend personeel bij de werkstations. Dus bijvoorbeeld het gedeelte van de fabriek dat schoonmaakt, heeft een R&D Process Engineer. Het gedeelte wat zich bezighoudt met lassen, heeft een Process Engineer. Zo kun je dat zien.
CS	Eén van de mannen op de spuiterij heeft een R&D functie. Hij is samen met een andere man van de spuiterij intern bezig geweest om een nieuwe oplossing te vinden voor het lakken.
ME	Maar naarmate je verder komt in het ontwikkelingsproces, kunnen mensen van andere afdelingen verbonden zijn omdat je meer specifieke kennis nodig hebt.

Appendix VI

To summarize all findings about the development process of process innovation, the following table is made (Table 1).

Table 1

The development process of process innovation through the lens of the Stage-Gate model

Stages	Activities
Idea/Discovery	Process innovation ideas mostly stem from product innovations. Product innovations are often conceived based on customer needs. This makes that the attention in this stage is focused on the new product. Also government policies and innovations at suppliers can lead to new ideas. The interviews give the impression that ideas for innovations arise in an unstructured way. In this stage the project has not yet begun. All employees of the company can contribute their creativity and expertise. The way ideas are generated is not easily to describe in a systematic manner.
1. Preliminary Assessment	In this stage the cost price of the new product is estimated and the preliminary ideas for production are investigated. In this stage a project plan is written that globally describes what the project entails. Based on this project plan the management decides whether the project can start.
2. Build business case	This stage entails the formal start of the project with regard to new product/process development. In this stage the project plan has to be elaborated and a business case is made. Often a test specimen is built that is intended to serve as proof of concept. If it turns out that a new production step is needed, the help of a supplier is required. The outcome of this stage depends on internal R&D activities involving various employees and external parties (e.g. supplier).
3. Development	At the end of stage 3 a final prototype of the product is made. After the prototype is made, production engineers determine which technical requirements the production process must meet. Several respondents have indicated that they design their own production line and manage their own machinery. When it appears that a new production step is needed, other companies are contacted to find a solution. All respondents indicated that they outsource the development of a new machine. Internal R&D activities are required to come to a suitable machine together with the supplier. The outcome of the negotiations is a quotation of the supplier. It

	is often a combination of a purchaser and an employee with technical knowledge (e.g. process engineer, production engineer, mechanical engineer) that together take the lead in these negotiations. Stage 3 ends when the supplier accepts the order to deliver the new machine. The quotations of the supplier also contain global agreements on how the machine will be tested.
4. Testing & Validation	After the supplier has accepted the order and the development of the new machine progresses, the supplier will refine the agreed tests. Ideally, a specific test is assigned to each requirement. Typically, the company accepts the machine after two tests are performed, the Factory Acceptance Test (FAT) and the Site Acceptance Test (SAT). During the development the company is given the opportunity to verify if the developments match the requirements. The purpose of a FAT is to verify if the equipment is ready for to shipment to the customer. During the FAT the supplier and customer are present. If a problem arises, the parties must meet again to discuss how the situation should be addressed and to decide how the functionality of the new machine can be corrected.
5. Full Production & Market Launch	In this stage the machine is incorporated in the production line. In the factory a so-called Site Acceptance Test (SAT) is performed before full production can be started. This test addresses the functionality of the full production line, including the new machine. The SAT often requires de production of 0-series. When it appears that the 0-series has successfully been produced, full production is switched on. The quotes show that a project ends when the new products brought to the market. After entering full production, actions are undertaken to organize the production process even more efficiently. Projects that only aim to increase efficiency are realized by a team of production engineers and process engineers. No new machines are developed internally.
Post-Implementation Review	This stage involves the evaluation of the project and the product's performance. After this stage the project is terminated.