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Timing the Start of Material Substitution Projects: Creating Switching Options under Volatile Material Prices

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Abstract

Firms developing new products often face the challenge of making investment decisions under uncertain input-cost conditions due to the price volatilities of the materials they use. These decisions need to be made long before the final products are launched on the market. Therefore, firms who invest in the opportunity to switch materials in a timely manner will have the flexibility to react to material price changes and realize competitive advantages. However, volatile material prices may also cause a firm to delay investment. Using real-options reasoning, this article studies the influence of input-cost fluctuations on the timing decision to start new product development (NPD) and thus create the follow-on opportunity to later replace an existing product. A model that combines waiting and switching options to derive influencing factors of the flexibility value which triggers the investment is developed and tested on a sample of material substitution projects from manufacturing firms. The results show how price uncertainty of the new and the old material, their joint price development, the expected project duration, and competitive preemption are related to the propensity to delay the start of NPD. The findings provide new insights on how timing in adopting materials can be used to hedge exposure to volatile material prices. The insights are relevant for adopters and producers of new materials, as well as for policy makers who strive for supporting the diffusion of new materials.

Keywords: New product development, timing decisions, input-cost uncertainty, material substitution, real options

Introduction

The timing of investment in R&D is relevant to the performance of firms (Datar et al., 1997; Katila and Chen, 2008; Perillieux, 1987). Research emphasizing the role of uncertainty in timing investment decisions echoes the logic of option theory (Dixit and Pindyck, 1994). Uncertainty increases the value of holding the option and suggests delaying investment in order to maintain flexibility (McDonald and Siegel, 1986; Pindyck, 1993). However, since the multistage nature of the R&D process provides follow-on investment opportunities (Cassimon et al., 2004; Gamba and Micalizzi, 2007; Jägle, 1999; Lint and Pennings, 2001; Loch and Bode-Greuel, 2001), an initial foothold investment creates rather than sacrifices flexibility (Miller and Folta, 2002). Uncertainty, therefore, increases the value of multistage investments and suggests triggering R&D projects (Jensen and Warren, 2001; Lee and Paxson, 2001; Pennings and Sereno, 2011). The optimal time to start the development of a new product may depend on the value of developing it and the nested investment opportunity to later replace the existing product. Decision makers may intuitively consider the uncertainties that shape the value of these competing investment opportunities. In order to provide empirical evidence, this article examines the influence of these uncertainties, and the correlation between underlying assets, on the propensity to delay the development of a new product.

Research on technology diffusion suggests a delay between the availability of new technologies and their adoption by industrial firms (Cheng, 2012). However, empirical work on the factors that influence the point in time at which firms start the development of a new product is scarce. Afuah (2004) finds that start-up firms tend to adopt radical technological changes earlier than incumbent firms. However, context variables such as uncertainty remain unconsidered.

Hoffmann, Trautmann, and Hamprecht (2009) account for regulatory uncertainty as they investigate the timing of investments in the development of electrical power plants. In case studies, they observe that firms do not postpone investment under regulatory uncertainty if the projects secure competitive resources, leverage complementary resources, or alleviate pressure from stakeholders. McGrath and Nerkar (2004) study the motivation to invest in R&D options. They show that firms more likely take out a real technology option, the greater the scope of opportunity, the less the firm has already taken out prior options in new areas that could expire, and the higher the commitment of competitors to the new technological field. Nevertheless, multiple real options can complement each other by providing opportunities of switching under uncertainty (Anand, Oriani, and Vassolo, 2007). Switching options depend on uncertainties that are specific to the related investment opportunities (Stulz, 1982); the empirical analysis of McGrath and Nerkar (2004) focuses on uncertainty that is endogenous to the firm, which can be actively reduced, rather than on exogenous uncertainty. While further empirical evidence on the timing of NPD is missing, conceptual work accentuates the role of uncertainty in decisions to start NPD: uncertainty increases the value of deferring development (Lint and Pennings, 2001; Sanchez, 1993) and governs the transition to subsequent stages of the innovation process in order to create growth and switching options (Lee and Paxson, 2001).

This article adopts real-options reasoning (McGrath, 1999) to study whether firms account for uncertainties at the initiation of a multistage investment. The study considersinvestment in the development of a new product as exercising a waiting option and creating a growth option to subsequently commercialize the new product (Miller and Folta, 2002). In particular, it focuses on new product developments that are initiated to substitute existing products. In such cases, firms create switching options rather than simple growth options (Anand, Oriani, and Vassolo, 2007;

Oriani, 2007). This study argues that the start of NPD depends on the input-cost uncertainties of mutually exclusive assets, the correlation of the asset values, the time until the new product will be developed, and the opportunity of competitive preemption through early development. Unit costs are relevant for the sales performance of new products (Tatikonda and Montoya-Weiss, 2001). Uncertainty about the input costs arises when prices of materials needed to build a product fluctuate unpredictably (Dixit and Pindyck, 1994). Conceptual studies show that uncertainty about the input-cost conditions influences the propensity to develop a new product (Tyagi, 2006) and to trigger the development project (Pindyck, 1993; Schwartz and Zozaya-Gorostiza, 2003).

The goal of the study is to contribute to real-option theory by applying real-options reasoning to multistage investment decisions in the development of new products. To test the propositions, the study uses a dataset of 101 material substitution projects from 95 manufacturing firms. Material substitution is defined as the replacement of a product by one product that is based on a new material. Input substitution constitutes an important type of opportunity in many industries (Klevorick et al., 1995) yet is understudied as a research field. Moreover, due to shortened pricing contracts of raw materials, imbalanced supply and demand, and fundamentals of financial crisis, decision makers in manufacturing firms are challenged by increased fluctuations in material prices. Economic reports show that price volatilities appear for a broad variety of raw materials and price fluctuations vary in terms of intensity and occurrence over time (Commerzbank, 2012; WiWo, 2010). The analytical advantages of studying material substitution projects are that investment decisions are discrete, provide follow-on investment opportunities, and involve material price fluctuations as observable sources of input-cost uncertainty that are exogenous to the firm. Furthermore, the stream of payments into the material substitution project can be stopped in the case of failure (Adner and Levinthal, 2004). Real-option strategies as a means to hedge uncertain environments seem to be appropriate for firms operating in commodity-related manufacturing industries (Aabo and Simkins, 2005).

The research design of the study permits to contribute to the discussion on multistage investments and switching options (Anand, Oriani, and Vassolo, 2007; Miller, 2002; Miller and Arikan, 2004; Miller and Folta, 2002; Oriani, 2007; Vassolo, Anand, and Folta, 2004). First, the study uses real-option theory to derive factors that influence various option values in the decision to invest in NPD and integrate them in a model that shows the relations between these option values and the timing of investment. Second, the study contributes to the empirical literature on the influence of uncertainty on the timing of R&D investments at the product level, which has been missing so far (Cuypers and Martin, 2010; Levitas and Chi, 2010; Oriani and Sobrero, 2008; Reuer and Tong, 2007). The results shed light on decisions to start the development of new products under uncertainty and enhance the research field of competence substitution (Adner and Zemsky, 2006; Martin and Mitchell, 1998; McEvily, Das, and McCabe, 2000; Polidoro Jr. and Toh, 2011) using the factors of external uncertainty, competitive preemption, and development time and their influence on the initiation of technology-substitution projects.

The study is organized as follows. First, the literature on real-option theory, focusing on investment decisions in R&D, is reviewed. Following this, a model of material substitution projects is developed, and hypotheses are derived. Subsequently, the empirical setting and the regression results are presented. Finally, the implications of the findings are discussed.

Theoretical Background

Recent literature in strategic management uses real-option theory to analyse the characteristics of R&D investments, e.g. the frequency of investments in R&D (Cuervo-Cazurra and Un, 2010), the market value impact of R&D investments (Levitas and Chi, 2010; Oriani and Sobrero, 2008; Reuer and Tong, 2007), the portfolio effects of strategic alliances in R&D (Vassolo, Anand, and Folta, 2004), and the motivation to invest in R&D options (McGrath and Nerkar, 2004). Real-option theory overcomes the shortcomings of the net present value rule that suggests triggering an investment when the net present value is positive. Dixit and Pindyck (1994) emphasize that this investment rule assumes the investment to be reversible or, if irreversible, to be a now-or-never proposition. They discuss that investment opportunities can have the structure of contingent investment decisions, and, similar to the structure of financial options, provide the owner with the right but not the obligation to buy an underlying asset. The seminal paper by Myers (1977) emphasizes that call options on growth opportunities increase firm value. Kester (1984) was the first to show empirically that the value of growth options is a component of market value. The real options logic can be transferred to R&D investments: by a modest first investment, the firm holds the opportunity on a profitable investment at some later point in time (McGrath, 1997; Mitchell and Hamilton, 1988; Newton and Pearson, 1994). The downside risk is limited to the first investment, the price of the option (McGrath, 1997). The cost of developing a new product lets the net present value of the investment be negative, since there are no direct cash flows before commercialization. Real-option models, however, show that the value of this investment opportunity under uncertainty can be positive and motivate the firm to invest (Trigeorgis, 1996), since it provides opportunities of successfully reacting to environmental discontinuities. The development of a new product offers the strategic flexibility to decide whether and when a new product will be commercialized (Sanchez, 1993).

Four streams of conceptual research relate to the initiation of R&D as strategic investment decisions under uncertainty. One stream uses real-option theory to determine the value of competitive R&D projects (Childs, Ott, and Triantis, 1998; Childs and Triantis, 1999; Lint and Pennings, 2002). They show that switching option values between projects have an impact on NPD strategies. A second stream of research uses real-option theory to value initial investments in the R&D process under consideration of the multistage nature of the investment decision (Cassimon et al., 2004; Jensen and Warren, 2001; Lee and Paxson, 2001; Lint and Pennings, 2001; Loch and Bode-Greuel, 2001; Pennings and Sereno, 2011). A third stream of research stresses the role of the duration of development on the timing of multistage investments in R&D (Bar-Ilan and Strange, 1996, 1998; Majd and Pindyck, 1987; Pacheco-de-Almeida and Zemsky, 2003; Weeds, 1999). Finally, rather than evaluating real options with financial models, studies view investment in NPD as a process of strategic choices through an option lens (Bowman and Hurry, 1993; Hurry, 1994; Sanchez, 1993). In this perspective, successive investments in products that are based on alternative technologies provide the firm with options to switch product strategies over time (Bowman and Hurry, 1993). Combining these four research streams enables modeling investment in a new product as creating the opportunity to substitute an existing product on the market. Previous studies point to the value of follow-on opportunities and their impact on investment decisions (Kim and Kogut, 1996; Kogut, 1991; McGrath and Nerkar, 2004). In the face of uncertain input prices for the existing and the new technology, holding an opportunity to substitute technologies adds value (Miller, 2002).

R&D decision making often depends on the interaction of multiple real-option values (Oriani and Sobrero, 2008). Having an investment opportunity, the firm can delay the development of a new product under uncertainty and hold a *waiting option* (McDonald and Siegel, 1986; Pindyck, 1993). Investing in a new product provides a *growth option* to produce and commercialize it (Mitchell and Hamilton, 1988; Sanchez, 1993). Since both option values increase with uncertainty, the decision to invest or to wait about investment depends on the trade-off between the values (Fisch, 2008; Folta and O'Brien, 2004; Oriani and Sobrero, 2008). If the investment provides flexibility in alternative product design, the firm holds a *switching option* (Anand, Oriani, and Vassolo, 2007; Kulatilaka, 1986). In general, investment decisions at the product level may depend on embedded option values. Real-options reasoning suggests that decision makers (implicitly) recognize the factors that shape these option values and respond to the value of flexibility (McGrath and Nerkar, 2004). Real-options reasoning enables building a model of delaying the commitment of resources to the development of a new product.

A Real-option Perspective of Material Substitution

Substitution of Materials

New or improved materials provide advantages for products and motivate firms to substitute the materials that are currently used for a product (Edwards, 2004; Janszen and Vloemans, 1997; Jung, 2004; Tilton, 1984, 1991). Substitution of materials can take place in various applications. E.g. automotive industries use lightweight materials to replace traditional materials: Mercedes-Benz adopted aluminum for the chassis of the new SL in 2012. BMW adopted carbon fiber composites for selected parts such as the roof of the M3, and the company recently announced that the chassis of the mass-produced electric vehicle i3 and i8 will be made from this material. Similarly, producers of aircrafts, wind turbines, or sports equipment use the advantages of new materials and substitute existing ones to improve the performance of their products. However, in spite of technological advantages, firms do not seem to utilize new materials as soon as they are available (Eagar, 1995; Fischmeister, 1989; Musso, 2009). Empirical studies in material processing industries emphasize the importance of material price developments to the adoption of new materials (Eastin, Shook, and Fleishman, 2001; Holmes, 1990a, 1990b) and show at the industry level that price instabilities can impact the timing of material substitution (Messner, 2002). Due to the property of aluminum to transfer heat, increased copper prices can finally trigger R&D investments to replace copper by aluminum in areas such as heating, ventilation, air conditioning, and refrigeration. Producers of catalytic converters can take advantage of volatile material prices by switching between platinum and palladium as active agents (Hagelüken, 2005). Applications of real-option theory to natural resource investments show that material price fluctuations substantially influence investment values (Brennan and Schwartz, 1985; Cortazar, Schwartz, and Casassus, 2001; Paddock, Siegel, and Smith, 1988) and influence the timing of investments (Moel and Tufano, 2002). Furthermore, input prices are thought to have a strong impact on flexibility values, and to be the decision basis for material changes in product design (Kulatilaka, 1986, 1988). As such, the ex-ante value of flexibility is supposed to trigger a material substitution project.

Model

We assume that the performance-cost relation qualifies a new material as a substitute for an old material. Consider a firm that plans to develop a new product that is based on a new material. Once the planned date to start the NPD arrives, the firm has to decide whether to release or delay the project. As the firm invests in the adoption of the new material, it gains the opportunity to replace the product version that is currently on the market. The firm has the choice to invest in developing the new product (suffix *N*) or preserve this opportunity for later and maintain the old product (suffix *O*). The waiting option value *D* decreases as the duration of the investment project *T* rises (Bar-Ilan and Strange, 1996; Pacheco-de-Almeida, Henderson, and Cool, 2008). If the firm exercises the waiting option to develop the new product, it obtains an option to grow by commercializing the new product G_N (Kester, 1984). By investing now, the firm gains the value of the immediate growth option G_{NI}. If the firm delays investment, it holds the waiting option *D* and will have access to a delayed growth option G_{ND} (Fisch, 2008; Miller and Folta, 2002). The firm will delay investment if the value of immediate investment is smaller than the value of delayed investment.

$$G_{NI} < D(T) + G_{ND}\,. \tag{1}$$

The opportunity to preempt competitors increases the growth option value of immediate investment (Folta and O'Brien, 2004; Miller and Folta, 2002). A head start ($h > 1$) in NPD makes an early growth option more valuable than a late one ($G_{NI} > G_{ND}$). G_{NI} is substituted for hG_N and G_{ND} for G_N and inequality (1) is rewritten as:

$$h \cdot G_N < D(T) + G_N\,. \tag{2}$$

A firm will defer investment if the total investment value *V* is smaller than zero:

$$V = -D(T) + (h-1)G_N < 0\;. \tag{3}$$

The existing product also contains a growth opportunity. Once the firm has invested in NPD, it possesses two growth options G_N and G_O. Since the product with the new material will be developed to replace the existing product with the old material, both investment opportunities G_N and G_O are mutually exclusive, and the firm has created an option to switch from the old to the new technology (Kulatilaka and Trigeorgis, 1994). As a switching option on two technologies is an option on the difference between the values of two risky assets (Oriani, 2007), the growth option value G_O has to be subtracted from the total investment value of inequality (3):

$$V = -D(T) + (h-1)G_N - G_O < 0 \ . \tag{4}$$

A switching option consists of two competing growth options (Anand, Oriani, and Vassolo, 2007). Before the investment rule can be finalized, a component that accounts for the correlation between the sources of uncertainty of both assets needs to be added. Generally, the underlying uncertainty of both values is determined by material price fluctuations. Correlation impacts the difference of the two assets, and thus the switching option value (Margrabe, 1978; Stulz, 1982). Therefore, a portfolio effect of the competing investments needs to be considered, and the portfolio effect *PE* (Vassolo, Anand, and Folta, 2004) is subtracted from inequality (4).

$$V = -D(T) + (h-1)G_N - G_O - PE < 0 \tag{5}$$

Hypotheses

Analogue to financial call options (Black and Scholes, 1973), the owner of a real option has the right but not the obligation to buy a real asset. By investing in the development of a product that builds on a new material, a firm exercises the option to invest and abandons the possibility to wait for more information on the evolution of material prices (Dixit and Pindyck, 1994). Having invested, the firm bears the risk of up- and downside developments of material costs, which impact the expected revenue distribution. Alternatively, the firm could keep the waiting option *D* (McDonald and Siegel, 1986; Pindyck, 1991), wait for new information (Dixit and Pindyck, 1994), and delay the commitment of resources to develop the new product (Sanchez, 1993). Input-cost uncertainty makes it less attractive to invest in R&D now (Pindyck, 1993). Previous studies show that uncertainty about the price of material inputs is negatively related to investment in manufacturing industries (Huizinga, 1993). Under uncertainty, firms tend to defer investment (Folta, 1998; Folta, Johnson, and O'Brien, 2006). According to inequality (5), it can be expected that price uncertainty of the new material $\sigma(p_N)$ has a deterrent effect on investment in the development of a new product.

H1: Price uncertainty of the new material increases the propensity to delay the start of NPD.

The expected time between the start of NPD and the arrival of first cash flows can take from a few months up to several years, as it does in the case of new material adoption in aerospace applications. Postponing the start of NPD will lead to a delay in marketing the product and earning the first cash flows (Pacheco-de-Almeida and Zemsky, 2003). However, under uncertainty, a long development time offers more opportunities to abandon the project when conditions turn unfavorable. By truncating bad outcomes, the expected profits of the project increase. Consequently, the decelerating influence of uncertainty through the waiting option D is offset by a long lag between investment and cash flows (Bar-Ilan and Strange, 1996). Previous studies show that time-to-build reduces the propensity to defer investment projects under uncertainty (Pacheco-de-Almeida, Henderson, and Cool, 2008). Thus, it can be expected that the interaction of material price uncertainty $\sigma(p_N)$ and the length of planned development time T will negatively influence the delay of NPD.

H2: A long expected development time reduces the positive effect of new material price uncertainty on the propensity to delay the start of NPD.

Investments in R&D provide growth opportunities that can be substantial in magnitude (Kester, 1984) and exceed the value of deferring investment if the firm has the opportunity to gain a strategic advantage (Kulatilaka and Perotti, 1998). Having invested in NPD early enables the firm to preserve a growth option value G_N by preempting competitors (Miller and Folta, 2002), avoid technological lockout (Ghemawat, 1991), prevent competitors from entering the market, or force them to "make room" in the market (Kulatilaka and Perotti, 1998). Preemption at an early stage of NPD provides an early-mover advantage and timing flexibility at subsequent stages, in particular, commercialization (Smit and Trigeorgis, 2007). Since downside risk is limited to the development cost and upside potential is unlimited, the growth option value will increase with uncertainty (Amram and Kulatilaka, 1999) and can exceed the value of the waiting option to invest (Oriani and Sobrero, 2008). Previous studies find a positive effect of R&D (as growth options) on market value (Reuer and Tong, 2007) and show an influence of uncertainty on the balance of waiting and growth option values that can be positive (Folta and O'Brien, 2004). In other studies, the accelerating influence of growth options overrides the decelerating influence of waiting options in the presence of a moderator variable that drives the growth option value such as market growth (Oriani and Sobrero, 2008) or competition (Fisch, 2008). Therefore, it can be expected that material price uncertainty $\sigma(p_N)$ has a negative impact on the delay of NPD when the firm has a head start over its competitors ($h > 1$, cf. inequality (5)).

H3: Under new material price uncertainty, competitive preemption reduces the propensity to delay the start of NPD.

Firms' R&D programs often search for designs that relate closely to the design incorporated in existing products (Martin and Mitchell, 1998), which can lead to a delay of the adoption of an emerging technology (Eggers and Kaplan, 2009). Thus, as an alternative of immediate material substitution, firms can also continue to improve the old product generation (Dierickx and Cool, 1989; McEvily, Das, and McCabe, 2000). Capabilities to process the old material represent a platform for future opportunities (Kogut and Kulatilaka, 1994, 2001). Technological progress concerning the old material bears further opportunities. Hence, the firm holds a growth option on lower cost or improved quality for future generations of the old product (Trigeorgis, 1996). Experience with the old material enables the recognition of valuable growth options (Bowman and Hurry, 1993; Folta and O'Brien, 2007). The source of these growth opportunities may stem from fluctuating input costs. Uncertain cost conditions of new products have an asymmetric effect on expected profits: While the downsides are limited, firms can benefit from favorable cost conditions (Tyagi, 2006). It can be assumed that investments to advance the old material are small in comparison to adopting the new material and do not create a substantial value of waiting under uncertainty. Rather, price uncertainty $\sigma(p_O)$ enhances the growth option value G_O of the old material and delays NPD.

> *H4: Price uncertainty of the old material increases the propensity to delay the start of NPD.*

A firm that has the flexibility to switch to the less costly of two input factors holds an option on the minimum of two risky assets (Loubergé, Villeneuve, and Chesney, 2002). Options whose payoffs depend on more than one underlying risky asset are modeled by exchange options (Johnson, 1987; Margrabe, 1978; Stulz, 1982). The value of an option on the minimum of two risky assets is influenced by the correlation between the two assets. Stulz (1982) shows that for a price correlation of -1, the option on the minimum of two risky assets is worthless. A strong negative correlation of prices increases the probability that one asset value is below a certain level, while the other asset is valuable. A less negative correlation of prices increases the switching option value of choosing the minimum of two risky assets. The switching option value is highest if the correlation coefficient is one. Stulz's (1982) argument of switching options contradicts the portfolio logic of Markowitz (1959). Minimum options constitute potential cost savings of investing in two competing technologies: An increase in correlation between the sources of uncertainty of both technologies raises the probability of cost savings provided by the minimum option (Goldenberg, 2010). Less correlation increases the risk of a reversed price relation and therefore increases the investments that are necessary for maintaining the switching option until the favorable material is clear. Therefore, it can be expected that the correlation of material prices ρ_{NO} will negatively influence the delay of NPD.

> *H5: Correlation between the price developments of the new and the old material reduces the propensity to delay the start of NPD.*

Altogether, the value of the switching option V depends on the uncertainty of the price of the new material $\sigma(p_N)$, on the interaction of new material price uncertainty $\sigma(p_N)$ and length of development time T, on the interaction of new material price uncertainty $\sigma(p_N)$ and the firm's competitive head start h, the uncertainty of the price of the old material $\sigma(p_O)$, and the correlation ρ_{NO} between the prices of new and old material. The probability that inequality (5) is true and the firm delays development is approximated by:

$$\text{Prob}(d) \approx \beta_0 + \beta_1 \cdot \sigma(p_N) - \beta_2 \cdot \sigma(p_N) \times T - \beta_3 \cdot \sigma(p_N) \times h + \beta_4 \cdot \sigma(p_O) - \beta_5 \cdot \rho_{NO}\,;\ \beta_i > 0 \qquad (6)$$

Methods

Data and sample

Testing hypotheses on the start of NPD projects in the context of material prices and technological competition involves a number of challenges. Secondary data on raw material prices are publicly available, however, firms mainly use customized and processed materials that are not traded at material exchanges. Patents are generally useful to analyze technological competition, however, material replacements do not qualify for patents. In some industries such as pharmaceuticals, early stages in the product development process are recorded in databases. Other manufacturing firms do not report on the start of NPD. Much less, they report on delays in the initiation of new projects. To collect information on price developments and competitive moves that are relevant to the delay of distinct material substitution projects, a primary data set by means of a survey was generated. Since material substitutions occur in different industry contexts but bring about similar commercial opportunities (Klevorick et al., 1995), material substitution projects are investigated across industries.

A survey instrument to raise data on material substitution projects was developed. To reduce inconvenience for informants and to increase their willingness to provide information (Huber and Power, 1985), the required information was collected by using a seven-point Likert response format. Because objective information such as price developments is asked for, multiple items are not needed. Planned and actual dates of starting the NPD projects where coded as monthly calendar figures. As such, they help avoid common method bias, which occurs when construct measures are similar (Podsakoff et al., 2003). To design the questionnaire, explorative interviews at industry fairs and conferences were conducted. A first draft of the questionnaire was presented to ten industry experts who are familiar with material substitution. Their feedback was used to improve the wording, to add items, and to optimize the format. Finally, the questionnaire was discussed with academics from engineering, business administration, and material sciences, as well as with industry representatives from different corporate functions. The questionnaire was pretested on six material substitution projects.

To identify informants in manufacturing firms, we proceeded in two steps. First, a list of the Association of German Engineers (VDI) was scanned, and 37 networks of firms that are likely to process new materials were selected. The managers of these networks were contacted to discuss the relevance of the topic to their member firms. In a second step, the network managers who identified material substitution as a relevant activity were asked to forward the questionnaire to company representatives who are in charge of such projects. Doing so, the probability of identifying persons who are responsible for material substitution projects and are motivated to take part in the survey was increased (Huber and Power, 1985). Among the contacted network managers, 22 agreed on forwarding the questionnaire to members of the network.

In total, 129 questionnaires were received. Among the respondents, 40 percent were CEOs or board members, 35 percent were senior executives, and the remaining 25 percent were heads of department or project leaders. Respondents were contacted to provide missing data and to ensure that they are knowledgeable about the project (Kumar, Stern, and Anderson, 1993). Anonymity and confidentiality of data handling were guaranteed. While some respondents turned out as not to be familiar with the material substitution projects or answered regarding an average of several substitution projects, other companies refused to supply missing data. Finally, usable questionnaires on a sample of 101 material substitution projects from 95 companies were obtained. The sample includes 36 running, six abandoned, and 59 completed projects. To check for response bias, the mean values of early and late responses by *t*-tests were compared - no significant differences were found. Table 1 presents the sample characteristics.

Insert Table 1 here

Measurement

Dependent variable. In the survey, respondents were asked to choose one recent material substitution project. The questionnaire asked for the planned starting date of the project and the date at which development actually started. The binary dependent variable *delay* is one if the company has delayed the start of NPD, and zero otherwise.

Independent variables. The variables *volanew* and *volaold* represent the material price uncertainties. Technology investment decisions are based on managerial perceptions (Ginsberg and Venkatraman, 1992). As managers make decisions regarding the uncertainty they perceive (Miller, 1993), earlier real-option studies at the project level use perceptual measures to capture uncertainty (Guiso and Parigi, 1999; Jiang, Aulakh, and Pan, 2009). Uncertainty arises when prices of materials needed to build a product fluctuate unpredictably (Pindyck, 1993). Volatilities of material prices seem to vary in terms of intensity and occurrence over time (Commerzbank, 2012; WiWo, 2010). Respondents were asked to indicate the material price fluctuations (1 = very low to 7 = very high) of the new and the old material before the start of NPD. The variable *matpricecorr* captures the link between the price fluctuations of the alternative materials, indicating the correlation of the expected returns of the underlying assets (Anand, Oriani, and Vassolo, 2007). Respondents were asked to evaluate the joint price development of both materials on a seven-point scale (-1 = in opposite directions to 1 = in the same direction). The duration of NPD *devtime* is measured by the difference between the planned start date and the planned completion date of the project in months (Swink, 2003). The variable *preemption* holds the preemptive effect of NPD in terms of strategic advantage (Lieberman and Montgomery, 1988). By preemption, a firm can secure its growth option and reduce competitors' growth options (Miller and Folta, 2002). Respondents were asked to indicate whether the firm has started the development before its strongest competitor. In this case, *preemption* equals one, and is zero otherwise.

Control variables. As firms seem to delay development in the face of technology switching costs (Weiss, 1994; Musso, 2009), the study controls for the investment necessary to develop and produce the product based on the new material. A formative measure with four items was used to cover diverse cost components; the items were totaled to obtain the variable *invest* (e.g. Cannon and Homburg, 2001; Mooi and Ghosh, 2010). Respondents indicated the intensity of the items: "Amount of adjacent parts affected by the material change", "Investment necessary to process the new material in serial production", "Degree of re-training or hiring new employees necessary to utilize the new material", and "Degree of initiating new sourcing procedures and contracts due to switching materials" (1 = low to 7 = high). The indicator collinearity for the items of the cost construct was assessed (Diamontopoulos and Winklhofer, 2001). Since the maximum variance inflation factor was 1.73, each item was far below the commonly accepted threshold of VIF > 10. Therefore, items did not have to be eliminated. Finally, the sum of the items was divided by the number of items. The variable *expnewmat* captures the firm's experience in applying the new material. Mitchell (1989) suggests that experience with a new technology in other products accelerates the start of NPD. In spite of this, real-option logic suggests that technical uncertainty makes the difficulty of an R&D project unpredictable, and that there is no use of waiting if investing reveals new information to the firm (Pindyck, 1993). According to this argument, firms will not hesitate about investing in NPD when they lack experience with the new material. Respondents indicated their acceptance of the sentence "We have already used the new material in other applications" on a seven-point Likert scale (1 = strongly disagree to 7 = strongly agree). Firms refrain from investing in R&D projects when financial resources are scarce (Cuervo-Cazurra and Un, 2010). For the variable *finresources*, respondents indicated whether they agreed on that "Ensuring financial resources for the NPD project was easy" (1 = strongly disagree to 7 = strongly agree). Family firms tend to hold options open (Ward, 1997), are more sensitive to uncertainty (Bianco et al., 2012), and may be more careful about replacing materials. The binary variable *famown* equals one when the firm is family-owned, and zero otherwise. Institutional arrangements may urge the firm to complete a NPD project once it has been started (Dixit and Pindyck, 1994). To operationalize the variable *obligation*, respondents were asked to indicate the obligation to finalize the project on a seven-point Likert scale (1 = low to 7 = high). The variable *matcostshare* controls for the importance of the material substitution to the product, since many firms use the cost-plus approach as a pricing strategy (Coe, 1990; Noble and Gruca, 1999). Respondents indicated their acceptance that "The price of the new material decisively affects the price of the new product" (1 = strongly disagree to 7 = strongly agree).

Analysis and Results

Table 2 reveals the descriptive statistics. Out of the 101 material substitution projects under observation, 49 were delayed, and 52 were started as planned. The length of development time (*devtime*) ranges from 1 month to 95 months. Respondents used the entire scales to indicate their acceptance of the sentences in the questionnaire. Only *matpricecorr* was not evaluated as -1, since the prices of substitute materials are positively related in a balance of supply and demand. The variable *matcostshare* has a mean of 5.38. This shows that, on average, the material substitution plays an important role for the products. The dependent variable and the independent variables show a reasonable variance. The variance inflation factors (VIF) are low and indicate little problems of multicollinearity.

Insert Table 2 here

In Table 3, logit models are used to test whether the model variables impact the decision to start development at the planned date or later. The explanatory contribution of the variables is tested by likelihood ratio tests. Nonlinearity in logit models means that the relationship between a change in the independent variable and the estimated change depends on the change in the variable of interest, the amount of change, and the level of all other variables in the model (Long and Freese, 2006). Furthermore, the marginal effects of the explanatory's variables need to be analysed over its range of variation (Hoetker, 2007, Wiersema and Bowen, 2009).

Insert Table 3 here

Model 1 is the base model. It includes the control variables and the simple effects of development time (*devtime*) and *preemption*. The log-likelihood is 14.30, McFadden's pseudo R squared is 0.10. Neither moderator variable is associated with *delay*. Model 2 adds the variable *volanew*. The price uncertainty of the new material shows no significant influence on the start of development; the marginal effects over the range of variation and the marginal effect at variable means are also insignificant. However, under the control of all other value components of inequality (6) as in Model 7, the coefficient is significant and positive as expected. Therefore, H1 is conditionally supported. The interaction of *volanew* and *devtime* in Model 3 produces a significantly negative coefficient. Fig. 1 shows that as *volanew* increases, the probability of delay increases less when *devtime* is high (75^{th} percentile) than when it is low (25^{th} percentile). Furthermore, the marginal effects are negative and significant when development time is long. The coefficient of *volanew* becomes significantly positive. A long development time seems to reduce the propensity to delay the start of NPD under uncertainty of the new material price. As the log-likelihood (21.39) is significantly higher than in Model 2, support for H2 is found. The results of Model 3 and Model 7 also show that under consideration of the interaction effect the simple effect of *devtime* is significantly positive. Hence, the probability of delaying NPD is higher for long development times than for shorter ones. The theoretical insight of this additional result will be discussed in the contribution section.

Model 4 tests whether the interaction of *volanew* and *preemption* lowers the threshold to start development. The interaction effect is significantly negative; the opportunity of competitive preemption seems to be an incentive to start a material substitution project under new material price volatility. Fig. 2 shows that without a head start before competitors, the probability to delay the start of NPD increases as *volanew* increases. By contrast, when the firm can preempt its competitors, the propensity to delay decreases as *volanew* increases. In addition, the likelihood ratio test shows a significant improvement of 3.94 compared to Model 2, supporting H3. Model 5 shows a positive and significant effect of the price uncertainty of the old material *volaold* on *delay*. Since the marginal effects over the range of variation and the marginal effect at variable means are significant and the log-likelihood is significantly higher than in the base model, support for H4 is found: firms seem to delay the start of NPD if the price of the old material is uncertain. Finally, Model 6 tests whether material price correlation (*matpricecorr*) reduces the propensity to delay the start of development; the effect is negative but insignificant (p = 0.155). However, under the control of all other value components of inequality (6) as in Model 7, the coefficient is significant and negative as expected. Therefore, H5 is conditionally supported.

Insert Figure 1 and 2 here

Looking at the control variables, a lack of financial resources (*finresources*) is associated with project delay. It seems that *family* firms are more likely to delay NPD. The marginal effects of *finresources* and *family* are also significant at sample means.

Discussion

The study investigates the impact of input-cost uncertainty on the start of NPD. A real-option model is developed and tested on a sample of material substitution projects. The study predicts and finds that a long development time reduces the propensity to delay development under volatile new material prices. Competitive preemption increases the incentive to trigger the investment under price fluctuations of the new material. Under material price fluctuations of the old material, firms hesitate about starting development. Controlling for competitive preemption, the results show that fluctuations of the new material price induce a delay of NPD. The correlation between the new and old material prices increases the incentive to trigger the development project.

Theoretical Contributions

The findings contribute to the existing literature in several ways. First, the study extends the empirical research on firm investment in R&D as real options (Cuervo-Cazurra and Un, 2010; Levitas and Chi, 2010; McGrath and Nerkar, 2004; Oriani, 2007;) by reducing the gap of studies at the project level, which has been frequently noted by real-options researchers (e.g. Cuypers and Martin, 2010; Oriani and Sobrero, 2008; Reuer and Tong, 2007;). Second, the article supplements the conventional view of waiting options in R&D. Simulation models posit that firms refrain from investing in NPD under uncertainty (Lint and Pennings, 2001; Pindyck, 1993). By controlling for the obligation to finalize NPD, this study finds empirical evidence for the argument of Bar-Ilan and Strange (1996) that the opportunity to abandon a project reduces the propensity to wait under uncertainty. This result is in line with the study of Pacheco-de-Almeida, Henderson, and Cool (2008) on the timing of investment in petrochemical plants; investment in the development of a new product under uncertainty is more likely when the duration of development is long. While their study focuses on one asset, we provide empirical evidence for two mutually exclusive assets. The results additionally show that, in contrast to their study, the length of the development time has a positive rather than a negative simple effect on the propensity to delay the start of a project. This finding is surprising and has not been part of the theorizing section, but provides an important contribution in terms of a combined real-option and resource-based perspective: Since it takes time to switch between capabilities (Dierickx and Cool, 1989), more time required to change technologies increases the expected switching cost (Kogut and Kulatilaka, 2001), and increases the propensity to delay the start of the material substitution project. This insight extends the understanding of the role of time-consuming resource accumulation (also referred as ‘investment lag’) in management research: For projects that create the follow-on opportunity to switch competences, resource accumulation lags favor using current capability and hesitate proactively building new capabilities.

Third, the results provide factors that suggest triggering investing and proactively creating the opportunity to substitute competences. The findings enhance the on-going discussion about competence substitution (e.g. Martin and Mitchell, 1998; McEvily, Das, and McCabe, 2000; Polidoro Jr. and Toh, 2011). In particular, McEvily, Das, and McCabe (2000) argue that delay in technology substitution reduces competitors’ efforts to compete. The article follows previous conceptual studies (e.g. Kulatilaka and Perotti, 1998; Miller and Folta, 2002) and argues that early investment under input-cost uncertainty improves a firm’s growth options and reduces competitors’ options. Early exploration of new technologies will enable a firm to learn and hold a competitive advantage by having the opportunity to substitute technological competences under volatile input cost. Thus, the study shows how the exploration of new technologies in parallel with the exploitation of existing competence (cf. March, 1991) is related to external uncertainties of underlying assets and competition.

Fourth, while previous research studies the timing of product substitution in the phase of market introduction (Cohen, Eliashberg, and Ho, 1996; Saunders and Jobber, 1988, 1994), this article extend this literature with insights on factors that shape switching options and influence the creation of follow-on opportunities to replace existing products. Building on the simulation model of Lee and Paxson (2001), this study argues that firms exercise waiting options early in order to gain access to switching options. As a complement to their model, this article includes the growth option of the technology that is presently in use. We show empirically the impact of input-cost uncertainty on the timing of creating switching options, as was suggested by theoretical work (Kulatilaka, 1986; Miller, 2002). The switching option is composed of two growth options (Anand, Oriani, and Vassolo, 2007) that relate to different sources of uncertainty. This design allows for integrating price correlation in our empirical setting: This study includes the role of correlation between the uncertain underlying assets on the switching option value, which has been emphasized by financial exchange option models (Carr, 1988; Margrabe, 1978; Stulz, 1982) and applied to option models of R&D investment (Anand, Oriani, and Vassolo, 2007; Childs, Ott, and Triantis, 1998; Lee and Paxson, 2001; Lint and Pennings, 2002;). The study of Vassolo, Anand, and Folta (2004) empirically tested options on the maximum of several assets. This article examines investments in options on the minimum of mutually exclusive assets and found evidence to support Stulz's (1982) proposition that correlation increases the value of switching options. Although option values were not measured, it is shown that managers consider the factor of material price correlation in their decision to create switching options. The results seem counterintuitive on Markowitz's (1959) portfolio theory, which suggests that due to diversification effects a lower correlation of two investments increases the total value of investment. However, option theory assumes conditionally financed projects (Van Bekkum, Pennings, and Smit, 2009). Consequently, the value of minimum options is zero if the correlation is -1 (Stulz, 1982).

Fifth, the study contributes to the literature that combines strategy and technology investments under uncertainty (Bettis and Hitt, 1995; Wernerfelt and Karnani, 1987), and to empirical work on the timing of technology adoption in new products (Afuah, 2004; Musso, 2009). Contingent factors for pursuing alternative technologies in parallel are identified. The findings complement the literature on material substitution, which has so far centered on the question of *whether* to adopt (Farag, 2008; Maine, Probert, and Ashby, 2005;), by the question of *when* to adopt a new technology. The decision to trigger the NPD marks the finalization of the front-end phase and the transition to the development phase – this timing decision can be part of NPD gate decisions. Previous studies showed that firms need to gather information for NPD stages from outside the firm earlier than is the norm (Zahay, Griffin, and Fredericks, 2011). This study shows for material substitution projects how external information can be used to determine timing decisions in order to benefit from volatile material prices.

Practical Implications

The study provides implications for management and economic policy in times of highly volatile material prices. NPD managers who decide about product concepts should proactively think about design flexibility to benefit from input-cost developments by exchanging materials (Sanchez, 1995). Since the adoption of new materials requires the technical release of additional components and additional financial resources, and can increase the fear that substitutes existing competences, NPD managers need to convince opponents of new material adoption. The flexibility value of a material substitution project provides additional arguments to explicate organizational decisions. Option values and their influencing factors could also be used as additional decision components to pass gate criteria for transitions to the next stage in the development process (Cooper, 2008). Competitive preemption under volatile material prices suggests triggering the project. If competitors have already adopted the material, uncertainty suggests a delay of the NPD project. However, when the expected development time is long and prices fluctuate, a delay incurs the danger of being locked-in the existing technology. As an example, the automotive industry has hesitated about adopting carbon fiber composites for large-scale production until BMW preemptively announced to develop the chassis of the i3 out of the new material. Other manufacturers like Daimler, Audi, and VW followed BMW and announced initiatives to gain experience with the new technology. BMW’s decision can be seen as a preemptive investment under uncertainty and, at the same time, strategic move to make competitors’ knowledge stocks obsolete. The followers’ decisions will allow them to build capabilities processing the new material, create the opportunity to switch, and reduce inertia relying on experience of processing traditional materials. The factors identified in this study, namely material price developments, competition, and expected development time, help to determine the timing of projects at the planning stage and provide arguments to dynamically adjust a firm’s technology roadmap. The findings also provide implications for customer-supplier interactions of integrated material suppliers. Representatives of supplier’s NPD departments may discuss the potential of alternative materials with their customers. In addition to technical features, they should also use economic arguments of material price developments to promote a new (or an old) material.

Procurement managers should encourage material substitution in the case of material price fluctuations and support strategic decisions in NPD. Financial hedging of material prices is possible but not necessary when there is flexibility to postpone the buying decision (Chod, Rudi, and Van Mieghem, 2010). In times of volatile material prices, procurement is keen on reducing exposure to price fluctuations on raw-material markets. In addition to measures of financial risk management, commodity-related manufacturing firms can use strategic measures, i.e. timing flexibilities of NPD investment decisions, to hedge such exposure. They can use qualitative or quantitative analysis to continuously observe the influencing factors of the option value to substitute materials. In particular, price volatilities of potential substitutes, their correlation, a competitor’s timing decision, and the expected development time for different projects should be part of risk management analysis. Procurement should discuss insights from this analysis with NPD managers to coordinate NPD activities with opportunities of purchasing (alternative) input factors and build competitive advantages in substitution processes.

The study provides policy implications for different spheres of political activity. Policy makers responsible for economics and technology who seek to subsidize the diffusion of materials in new applications can use insights of this study to prioritize their activities. Under high uncertainty of new material prices, policy makers know whether early-moving firms have begun development activities or launched products. Potential followers may still hesitate because of volatile material prices. As firms with short development times are more likely to hesitate than firms with long development times, public funding institutions should center on supporting material substitution projects with a short development time.

In terms of trade policies, many countries are dependent on imports of raw materials. Access to strategic materials, such as noble earths, can influence the prices that evolve on markets. Foreign affairs policy that seeks to secure a prosperous economic environment for firms processing materials by influencing the supply of those materials should consider the role of input-cost volatilities and correlations of substitutes on investment. Furthermore, policies that are designed to reduce volatilities of certain materials (e.g. activities to balance and stabilize demand and supply) may have smaller effects for projects with short development times than for projects with long development times (cf. Bar-Ilan and Strange, 1996).

Limitations and Future Research

As one of the first attempts to investigate the delay of development projects under material price uncertainty, the study is subject to several limitations. Although managers make decisions based on their perceptions of environmental uncertainty (Miller, 1993), a critical point is using perceptual measures of uncertainty. Future studies may focus on material substitutions with commonly traded materials and proxy uncertainty as a conditional variance of price levels (Carruth, Dickerson, and Henley, 2000). A further limitation originates from the data structure of this study. With cross-sectional data, we cannot test for causal inferences. The study shows that it would be interesting to use longitudinal data to examine whether switching options impact the change of product strategies over time (Bowman and Hurry, 1993). The study lacks detailed information about the governance of the material supply transaction: As a limitation, it does not control for the strength of the ties to suppliers or for possible in-house production of the material, which may influence the flexibilities in making timing decisions. Furthermore, the study does not control for industry differences. Future studies on material substitution projects in certain industries could incorporate industry-specific effects, such as barriers to imitation that may lead to earlier investments in NPD (Pacheco-de-Almeida, Henderson, and Cool, 2008). Finally, after investigating the creation of a switching option through material substitution in this study, future research should investigate the exercise of the switching option by introducing the product on the market and evaluate its impact on innovation performance.

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Table 1: Sample Characteristics

Industry		Number of employees		Material substitution path	
Mechanical Engineering	28%	<50	17%	Metal → Metal	25%
Automotive	27%	50-500	29%	Metal → Plastics	23%
Chemicals	10%	501-5,000	29%	Plastics → Plastics	17%
Materials Technology	8%	>5,000	25%	Metal → Carbon fiber composites	11%
Electrical Engineering	6%			Metal → Glass fiber composites	4%
Medical Engineering	4%			Other	21%
Aerospace	3%				
Other	14%				

N = 101.

Table 2: Descriptive Statistics and Correlation Matrix

	Variable	Mean	SD	Min	Max	1	2	3	4	5	6	7	8	9	10	11	VIF
	delay	0.49	0.50	0	1												
1	*volanew*	3.44	1.56	1	7	1.00											1.15
2	*volaold*	3.98	1.73	1	7	0.04	1.00										1.09
3	*matpricecorr*	0.13	0.38	-0.6	1	0.15	0.08	1.00									1.16
4	*invest*	3.49	1.43	1	6.5	0.18*	–0.04	–0.22**	1.00								1.53
5	*devtime*	20.88	15.62	1	95	0.15	–0.05	0.03	0.29***	1.00							1.19
6	*preemption*	0.69	0.46	0	1	–0.01	0.00	–0.04	0.02	–0.11	1.00						1.05
7	*expnewmat*	4.50	2.49	1	7	0.08	–0.03	0.12	0.02	–0.04	–0.14	1.00					1.13
8	*finresources*	5.22	1.78	1	7	0.03	0.18*	–0.07	0.01	0.05	–0.06	–0.03	1.00				1.07
9	*famown*	0.55	0.50	0	1	0.05	–0.02	0.08	0.04	–0.05	0.05	–0.15	0.00	1.00			1.06
10	*obligation*	4.61	2.00	1	7	0.09	–0.09	–0.04	0.13	0.03	–0.08	0.22**	0.06	–0.08	1.00		1.13
11	*matcostshare*	5.38	1.77	1	7	–0.11	0.13	–0.04	0.37***	–0.04	–0.07	–0.03	0.09	–0.06	0.17*	1.00	1.34

$N = 101$
* $p < 0.1$
** $p < 0.05$
*** $p < 0.01$

Table 3: Logit Estimation of the Influence Factors on the Propensity to Delay the Start of New Product Development

delay	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
matpricecorr						-0.908	-1.546*
						(0.638)	(0.822)
volaold					0.323**		0.263*
					(0.137)		(0.147)
volanew × *preemption*				-0.620*			-0.830**
				(0.324)			(0.412)
volanew × *devtime*			-0.032**				-0.037**
			(0.014)				(0.017)
volanew		0.013	0.669**	0.461*			1.427**
		(0.142)	(0.309)	(0.280)			(0.559)
devtime	-0.001	-0.001	0.130**	-0.003	-0.001	0.002	0.149*
	(0.015)	(0.015)	(0.057)	(0.016)	(0.015)	(0.015)	(0.068)
preemption (0/1)	-0.404	-0.404	-0.566	-0.421	-0.450	-0.417	-0.643
	(0.469)	(0.469)	(0.501)	(0.487)	(0.485)	(0.474)	(0.560)
invest	0.124	0.122	0.142	0.098	0.150	0.065	0.018
	(0.173)	(0.175)	(0.185)	(0.181)	(0.181)	(0.177)	(0.204)
expnewmat	0.107	0.107	0.139	0.091	0.114	0.132	0.172
	(0.092)	(0.093)	(0.096)	(0.094)	(0.096)	(0.095)	(0.108)
finresources	-0.198	-0.199	-0.244*	-0.217*	-0.268**	-0.220*	-0.347**
	(0.122)	(0.122)	(0.131)	(0.126)	(0.131)	(0.125)	(0.146)
famown (0/1)	1.156**	1.153**	0.978**	1.106**	1.240***	1.266***	1.234**
	(0.449)	(0.450)	(0.465)	(0.459)	(0.469)	(0.463)	(0.524)
obligation	-0.007	-0.008	-0.107	0.011	0.033	-0.011	-0.049
	(0.115)	(0.115)	(0.124)	(0.119)	(0.121)	(0.116)	(0.135)
matcostshare	0.202	0.204	0.204	0.236	0.158	0.222	0.220
	(0.143)	(0.145)	(0.155)	(0.153)	(0.145)	(0.146)	(0.162)
LR	14.30*	14.31	21.39**	18.25*	20.20**	16.43*	33.11***
LR Test		0.01	7.08***	3.94**	5.90**	2.13	18.81***
Reference	no (base m.)	vs. model 1	vs. model 2	vs. model 2	vs. model 1	vs. model 1	vs. model 1
Pseudo R^2	0.10	0.10	0.15	0.13	0.14	0.11	0.23

N = 101
Standard errors in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

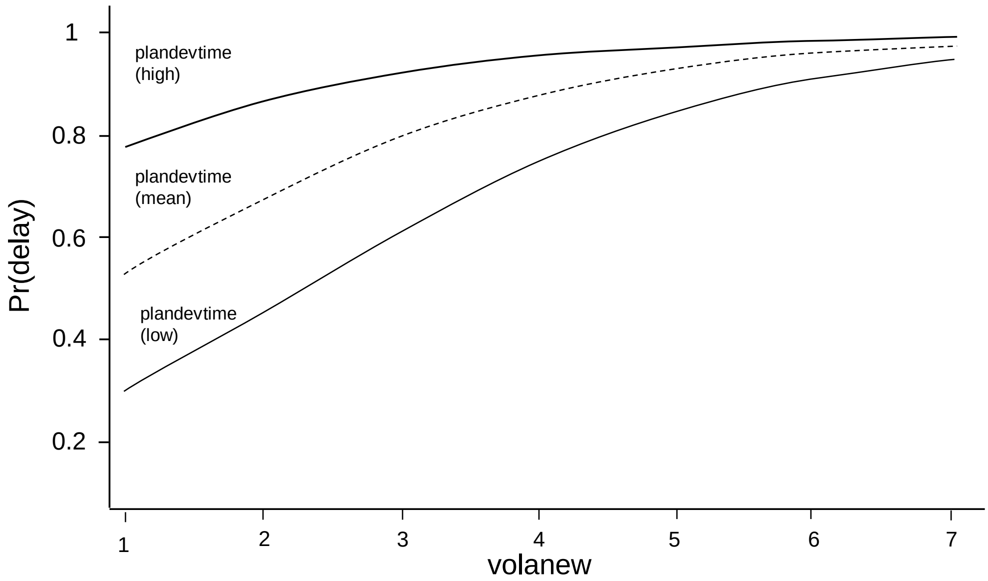

Figure 1: Relationship between new material price volatility and the propensity to delay the start of new product development under low and high planned development time

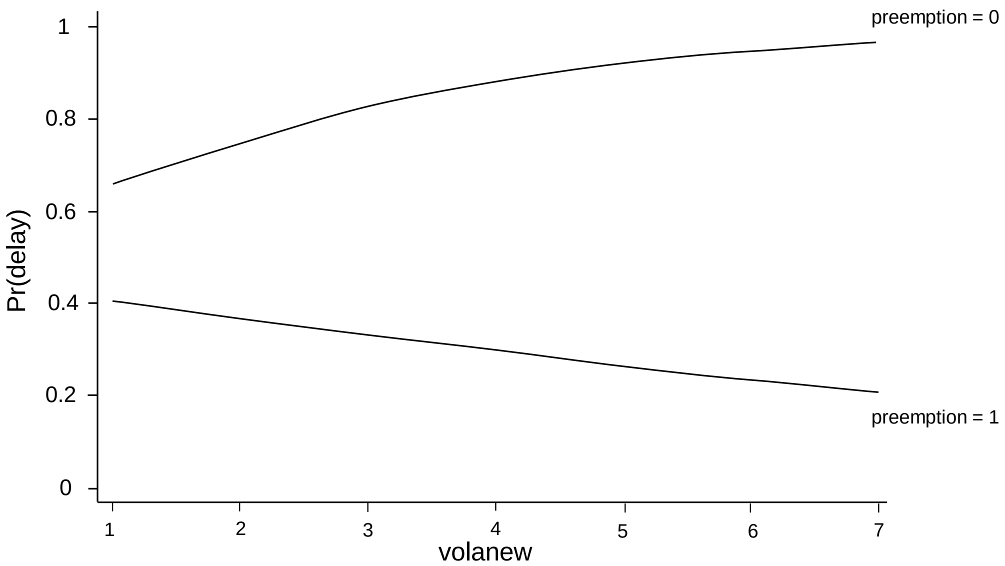

Figure 2: Relationship between new material price volatility and the propensity to delay the start of new product development under preemption and without preemption

Appendix. Measures

Variables	Operationalization
Dependent variable:	
startdelay	Dummy variable (1 = company has delayed the start of new product development; 0 otherwise)
Independent variables:	
volanew	„The price fluctuations of the new material before the start of new product development were …“ (7-scale: 1 = very low ; 7 = very high)
volaold	„The price fluctuations of the old material before the start of new product development were …“ (7-scale: 1 = very low; 7 = very high)
matpricecorr	„The price developments of the new and the old material were…“ (7-scale: -1,0 = in opposite directions ; 1,0 = in the same direction)
devtime	Time difference between the planned start date and the planned completion date of the project (months)
preemption	Dummy variable (1 = compared to the strongest competitor, we started developing a product with the new material earlier; 0 otherwise)
Control variables:	
invest	4 formative items: „Amount of adjacent parts affected by the material change“, „Investment necessary to process the new material in serial production“, „Degree of training or hiring new employees necessary to utilize the new material“, „Degree of initiating new sourcing procedures and contracts due to switching materials“ (7-scale: 1 = low; 7 = high)
expnewmat	„We have already used the new material in other applications“ (7-scale: 1 = strongly disagree; 7 = strongly agree)
finresources	„Ensuring financial resources for the new product development project was easy“ (7-scale: 1 = strongly disagree; 7 = strongly agree)
famown	Dummy variable (1 = firm is family-owned; 0 otherwise)
obligation	„Obligation of the firm to finalize the new product development project“ (7-scale: 1 = low; 7 = high)
matcostshare	„The price of the new material decisively affects the price of the new product“ (1 = strongly disagree; 7 = strongly agree)