Jan Hendrik Fisch and Jan-Michael Ross

Timing Product Replacements under Uncertainty: The Importance of Material' Price Fluctuations for the Success of Products That Are Based on New Materials

Article (Accepted for Publication)
(Refereed)

Original Citation:

This version is available at: http://epub.wu.ac.at/4386/
Available in ePubWU: November 2014

ePubWU, the institutional repository of the WU Vienna University of Economics and Business, is provided by the University Library and the IT-Services. The aim is to enable open access to the scholarly output of the WU.

This document is the version accepted for publication and — in case of peer review — incorporates referee comments.
Timing Product Replacements under Uncertainty –
The Importance of Material-Price Fluctuations for the
Success of Products that are Based on New Materials*¹

Prof. Dr. Jan Hendrik Fisch (corresponding author) *²
Faculty of Business and Economics, University of Augsburg
Universitätsstr. 16
86159 Augsburg, Germany
fisch@wiwi.uni-augsburg.de
Phone +49-(0)821/598-4080
Fax +49-(0)821/598-4220

Faculty of Business and Law, University of Newcastle, Callaghan,
New South Wales, Australia

Dr. Jan-Michael Ross *²
Imperial College Business School
London SW7 2AZ, United Kingdom
jan.ross@imperial.ac.uk
Phone: +44-(0)207/59-45105

*¹ We acknowledge the support received from Markus Mann (Deutscher Technologiedienst) to undertake this research. The authors are grateful to the editor of JPIM and anonymous reviewers for their help in improving this article.

*² The authors are listed in alphabetical order.
Biographical note:

Prof. Dr. Jan Hendrik Fisch holds the Chair of Innovation and International Management at University of Augsburg, Germany, and is Visiting Professor at University of Newcastle, Australia. He has a Diploma degree in Electronics and Business Administration from Technical University of Darmstadt, Germany, and a PhD from University of Hohenheim, Stuttgart/Germany. Before joining University of Augsburg, he was an Assistant Professor at University of Hohenheim and a Professor of Innovation Management at Zeppelin University, Friedrichshafen/Germany.

Dr. Jan-Michael Ross is a Research Associate at Imperial College London, United Kingdom. He holds a Diploma degree in Economics from University of Hohenheim, Stuttgart/Germany, and a PhD from University of Augsburg, Germany.
Timing Product Replacements under Uncertainty – The Importance of Material-Price Fluctuations for the Success of Products that are Based on New Materials

Abstract

Being first-to-market with new products is one of the most enduring pieces of strategic advice handed to managers. This view also emphasizes the importance of launching new products that are based on new materials as soon as possible. However, when the input costs of products that embody new materials are uncertain due to volatile material prices, the advantage of being an early mover comes along with the risk of paying unexpectedly high material prices. Real-option theory suggests delaying material substitution under uncertainty even if the new material enables superior product performance. Firms who have created the flexibility to switch between alternative inputs can benefit from responding to opportunities or threats that arise from changes in the environment. The current study formalizes this logic in a switching-option model and tests it on a sample of material substitution projects from the manufacturing sector. Our findings shed light on how input-cost fluctuations influence the timing-performance relationship and bring into question the common advice to launch new products as soon as possible. Instead, our results suggest that firms who align the timing of market launch to trends and fluctuations of material prices improve their competitive positions. These insights suggest novel ways for new product development (NPD) managers how to successfully use external information at the back-end of the NPD process and how to compete in an era defined by volatile material prices and technological change.

Keywords

Market launch, timing, performance, uncertainty, material substitution, real options
Introduction

Innovative materials improve the quality or reduce the cost of industrial applications. In spite of technical advantages, the commercial adoption of new materials can take about 20 years (Eagar, 1995; Maine, Probert, and Ashby, 2005). In the case of carbon fiber composites, the time-span between the first large-scale production in the 1960s and the decision of BMW to adopt this material for the chassis of the mass-produced electric vehicle i3 was nearly half a century. Other German premium-car manufacturers (Daimler, Audi, VW) followed BMW and announced initiatives to gain access and experience with this technology for large-scale production. Carbon composites have been used to build race cars and selected parts for two decades, however, these applications are realized by handcraft. While carbon fibers are still much more expensive than aluminum or steel, new technologies of processing carbon fibers and increasing steel prices since the world financial crisis make the new material relatively more attractive and motivate NPD managers to substitute materials.

As the carbon composite example shows, price changes of substitute material influence investment hurdles to adopt alternative materials for new products. Besides high costs, which are often prohibitive at an early stage (the price of carbon fibers has dropped in the meantime by more than 90 percent), future material prices can be uncertain. Firms who introduce materials as early movers bear the risk of paying material prices that thwart the advantages of a technological leader strategy (Lieberman and Montgomery, 1988). Staying flexible regarding material price changes and synchronizing material substitution with such changes (Kulatilaka, 1986) provides the innovating firm with cost advantages in material supply. Economic research into the timing of adapting innovative materials gives valuable insights for both adopters and producers of these
materials in times of volatile material prices, as these insights complement technical reasoning by a financial rationale.

Previous research points out that technological substitution often occurs by new product introduction and simultaneous deletion of the existing product generation (Cohen, Eliashberg, and Ho, 1996; Hise and McGinnis, 1975; Saunders and Jobber, 1988, 1994; Tushman and Rosenkopf, 1992). However, although the timing of market launch is a meaningful back-end NPD activity to improve the chances of new products on the market (Di Benedetto, 1999) and launch timing has been shown as an important factor in order to explain new product success (Calantone and Di Benedetto, 2012), the timing to release a new product generation based on a new technology is still an understudied element in the literature (Lawless and Anderson, 1996; Peres, Muller, and Mahajan, 2010).

While the conventional wisdom of practitioners suggests that generations will be substituted as soon as the new product is available (Peres et al., 2010), the optimal timing for product substitution can be later than the finish of development (Pae and Lehmann, 2003). Fear of cannibalization can be a reason to delay the launch of a new product generation (Wu, Balasubramanian, and Mahajan, 2004). Mitchell (1989) finds that firms will wait about introducing technically discontinuous products if their core products are not threatened. Once external events occur (e.g. competitive or complementary innovations), the likelihood of releasing a new product generation increases (Turner, Mitchell, and Bettis, 2010). Mitchell (1989) mentions that firms have to balance the incentive to take a strong position early and the incentive to wait about introducing a new product generation until uncertainties subside. Studies about firm-level investment decisions under uncertainty (Folta and O’Brien, 2004; Fisch, 2008)
show that this trade-off is of paramount importance. Empirical evidence of its relevance for product replacement decisions is lacking.

Dynamic environments influence the price building of input factors, and firms are challenged making investment decisions about the materials they use when their prices fluctuate unpredictably, hence, are uncertain. Tyagi (2006) argues that input-cost uncertainty at new product introduction increases the risk of market failure, since cost-conditions can turn out to be unfavorable and reduce profitability. Empirical studies show that unit costs are relevant for the sales performance of new products (Tatikonda and Montoya-Weiss, 2001). Higher variable cost than anticipated can induce NPD managers to delay switching to the new product. As a consequence, they are likely to treat the new product as an option on later market launch (Wu et al., 2004). The value of this option increases with input-cost uncertainty and suggests waiting to invest (Pindyck, 1993). However, high cost uncertainty can also incentivize firms to introduce new products: While the downsides are limited, since production can be stopped, cost uncertainty can increase the expected profits (Tyagi, 2006). These opposing effects spur the question under what input-cost developments does delaying the launch of a new product generation improve the competitive position.

This article centers on firms who have developed a new product in order to replace an existing product generation on the market. In a view of real options, the timing of market launch will be conditional on the uncertainty of input-cost developments. In particular, the study sheds light on how input-cost uncertainty moderates the timing-performance relation. Recent work shows that firms benefit from real-options reasoning in relation to options that are generally created to respond to variations in prices or demand with the goal of selling more profitable items (Verdu, Tamayo, and Ruiz-Moreno, 2012). Real-options seem to be particularly appropriate for firms
operating in commodity-related industries (Aabo and Simkins, 2005). Those industries are typically strongly exposed to volatile material prices. To test the propositions empirically, the study considers material substitutions as switching options in product design (Kulatilaka, 1986). The study extends previous switching-option models by including a growth opportunity that the material change offers. Recent empirical insights show how uncertainties of material price developments influence the propensity to initiate a product substitution project and to create an option to substitute materials (Fisch and Ross, in press). As a complement, this study seeks to improve our understanding of how the success of the timing of the launch (i.e. exercise of the switching option) is contingent on dynamic external factors. The findings show that the optimal timing of material substitution depends on the price trends of the new and old material, the price fluctuations of both materials, and the opportunity to preempt a competitor on the market. The insights from material substitutions are important for NPD managers who have to make decisions about the timing of market launch and product replacement under volatile input costs. The article shows how decision-makers can use this external information in later stages of the NPD process.

The study is organized as follows. First a real-option model of material substitution under material price uncertainty is devised. Following this, the model is used to derive hypotheses on the competitive impact of decisions to delay the market launch of products that are based on new materials. Subsequently, the empirical methods and results are presented. Finally, theoretical and managerial implications are discussed.

**Material substitutions as switching options**

*Model*
Economic models show that the relationship between material price developments and material substitution decisions is discrete and mostly irreversible due to technological progress and investment thresholds (Tilton, 1984, 1991). Industry-level studies stress the role of material prices for new material applications (Eastin, Shook, and Fleishman, 2001; Holmes, 1990a, 1990b) and show that price instabilities can influence material substitution processes (Messner, 2002).

The following model assumes that the performance-cost relation qualifies a new material as a substitute for an old material. Consider a firm that has finished the development of a product based on the new material, while the previous version of the product is still on the market. The firm can either launch the new product (suffix \( N \)) now or and wait and maintain the old product (suffix \( O \)). The value of an investment opportunity is given by the present value of the expected cash flows plus the value of the embedded growth opportunity (Kester, 1984). Essentially, the total value \( V \) of either product is given by the present value of the expected cash flows \( C \) plus the value of the related growth option \( G \), which mirrors the profit potential of future opportunities (e.g. to expand the production of a product in case of favorable conditions).

\[
\begin{align*}
V_N &= C_N + G_N \\
V_O &= C_O + G_O
\end{align*}
\]

As it is assumed that the new product is developed in order to replace the existing product, the firm will switch from the old product to the new product as soon if its total value exceeds the total value of the old product. The firm holds a real switching option on the difference between the growth option values of the new and the existing technology (Anand, Oriani, and Vassolo, 2007; Oriani, 2007). Switching between alternative technologies is favorable if the difference of
the present values and the value of switching is positive (Kulatilaka and Trigeorgis, 1994). In a similar way, introducing the new product based on a new material is beneficial if

\[ V_{SW} = C_N - C_O + G_N - G_O > 0. \]  \hspace{1cm} (2)

Having the flexibility to extend the life-cycle of the old product (and to launch the new product later) or to introduce the new product immediately reduces the exposure to fluctuating material prices. However, if alternative input prices are correlated, the variance of the price difference reduces, and the value of the switching option diminishes (Adkins and Paxson, 2011; McDonald and Siegel, 1986); holding the option and delaying the market launch of the new product is less beneficial. Correlation between the values of assets is an important source of switching option value within a portfolio of competitive investment opportunities (Anand et al., 2007). If the investment opportunities are mutual exclusive, the joint total value is less than the sum of the individual total values. Increasing correlation reduces the total value of the portfolio. This portfolio effect \((PE)\) is sub-additive for competing investments (Vassolo, Anand, and Folta, 2004). We account for sub-additivity in the portfolio of growth options by subtracting \(PE\) and rewrite inequality (2) as

\[ V_{SW} = C_N - C_O + G_N - G_O - PE > 0. \]  \hspace{1cm} (3)

Substituting materials in industrial products can be complex and expensive. If producing the new product requires purchasing new tools and machines (Weiss, 1994), adapting manufacturing processes (Musso, 2009), or acquiring new labor skills (Henderson and Clark, 1990), substantial investment is necessary and will be at least partly irreversible. Facing uncertainty, the firm will tend to wait about the investment, hold the waiting option and try to gather more information
(Dixit and Pindyck, 1994). In the model, the waiting option value \( D \) reduces the value of switching \( V_{SW} \):

\[
V_{SW} = C_N - C_O - D + G_N - G_O - PE > 0. \tag{4}
\]

Finally, a differentiation between acquiring the growth option of the new material \( G_N \) now or later is required. A head start \( h \) before competitors in entering the market makes an immediate growth option \( G_{NI} \) more valuable than a delayed growth option \( G_{ND} \) (Folta and O’Brien, 2004; Miller and Folta, 2002). Including the advantage through competitive preemption \( (h > 1) \), the early growth option \( G_{NI} = hG_N \) has a higher value than the late growth option \( G_{ND} = G_N \) (Fisch, 2008). The difference of both values is the growth option value which the firm obtains through early investment. First-mover advantages under uncertainty can be an incentive to launch the product early (Bstieler, 2005) and the source of the growth option value. Thus, the value of switching can be written by the inequality:

\[
V_{SW} = C_N - C_O - D + (h-1)G_N - G_O - PE > 0. \tag{5}
\]

\textit{Hypotheses}

The first value component of inequality 5 is the present value of the expected cash flows \( C_N \). It relates to the cost of the new material. A price increase of the new material raises the input cost of the product. A firm can pass the higher input price to customers. Through adding a profit margin to production cost (Coe, 1990; Noble and Gruca, 1999), it can pursue cost recovery goals (Lancioni, 2005). If customers are price sensitive (Tellis, 1988), fewer customers will purchase the product, and the present value of the new product \( C_N \) decreases. Higher unit costs than
targeted are negatively related to the sales performance of new products (Tatikonda and Montoya-Weiss, 2001). Alternatively, if the firm decides not to pass the increased input cost to customers, the profit margin reduces and the present value of the cash flow decreases as well.

Decreased profits increase the incentive to defer the market launch. Higher input costs than anticipated may motivate decision makers to keep the new product only as an option on market launch to be exercised at an appropriate time in the future (Wu et al., 2004). In this case the firm proceeds producing the old product based on the old material. If the firm immediately launches the new product at an increased price of the new material, it will realize reduced incremental cash flows from switching. Lower gains achieved from the price difference increase the risk that switching cost will not be covered, since material prices fluctuate and the switching is irreversible. The present value of the new product $C_N$ decreases when the trend of the price of the new material $\mu(p_N)$ is positive. Therefore a firm will improve its competitive position by delaying the replacement of the old product.

$H1$: Delaying the market launch under increasing prices of the new material improves the competitive position.

As in the previous case, a positive price trend of the old material $\mu(p_O)$ will diminish profits. Once a firm has built an opportunity to switch materials by means of product substitution, there is an incentive to switch as soon as possible, because the product substitution offers the opportunity to realize increased incremental cash flows. Since competitors are confronted with the same material price developments, the firm that is able to quickly substitute materials improves its competitive position. The reduced present value $C_O$ of the old product makes it
relatively less attractive, thus a soon replacement by the new product will be beneficial to the firm.

\[ H2: \text{Delaying the market launch under increasing prices of the old material deteriorates the competitive position.} \]

As price fluctuations impose a discount on future cash flows, the uncertainty of the price of a new material \( \sigma(p_N) \) decreases the present value \( C_N \). In addition, uncertainty suggests holding the option to launch the product instead of committing irreversible investments towards commercialization (Lint and Pennings, 2001; Sanchez, 1993). Cost uncertainty of materials delays investment in R&D (Pindyck, 1993) and the start of production (Pindyck, 2004). Uncertainty increases the variance of the relative values of the underlying assets and leads to higher value of the option (McDonald and Siegel, 1986). Previous studies show that, under uncertainty, firms hold the option to invest and defer market entry (Folta, Johnson, and O’Brien, 2006; O’Brien, Folta, and Johnson, 2003). Furthermore, investments in manufacturing industries seem to decrease under input price uncertainty (Huizinga, 1993). Due to the increasing waiting option \( D \) in inequality (5), we expect that delaying the replacement of the old product by the new product under material price uncertainty of the new material \( \sigma(p_N) \) improves the competitive position.

\[ H3: \text{Delaying the market launch under uncertain prices of the new material improves the competitive position.} \]
Launching the new product provides the firm with a growth opportunity. Under uncertainty, the value of the growth option $G_N$ can be substantial in magnitude (Kester, 1984; Myers, 1977) and compensate for the effects of higher discounts on future cash flows and the value of waiting. However, since there is the possibility that other firms will enter the market as well, this growth opportunity is not proprietary (Trigeorgis, 1996). If the firm is better able to capitalize on the new material application than its competitors (Kulatilaka and Perotti, 1998), the growth opportunity is likely to exceed the incentive to defer investment and prompt the firm to invest. In particular, the firm can preempt competitors and gain a first-mover advantage (Lieberman and Montgomery, 1988), dissuade competitors from entry, or force them to make room on the market (Kulatilaka and Perotti, 1998). Having a head start $h$ on the market, the firm will benefit from temporary monopoly rents (Miller and Folta, 2002). Previous studies support that competition erodes option values of deferring investment (Bulan, 2005), that the risk of preemption reduces the time available to exercise options (Jiang, Aulakh, and Pan, 2009), and that competition speeds up investments in order to obtain growth options (Folta and O’Brien, 2004; Fisch, 2008; Oriani and Sobrero, 2008). Bstieler (2005) observes that firms proceed with new product launches under uncertainty, as they expect to achieve first-mover advantages. A firm which has access to a growth option $G_N$ under material price uncertainty $\sigma(p_N)$ by preempting competitors $h$ will deteriorate its competitive position if it delays the launch of the new product.

**H4:** The interaction between competitive preemption, the delay of the market launch, and the price uncertainty of the new material influences the competitive position such that, ceteris paribus, the delay of the market launch and the price uncertainty of the new material have a smaller improving effect on the competitive position at high levels of competitive preemption.
In a similar vein, the value of keeping the previous product on the market depends on the uncertainty of the price of the old material $\sigma(p_O)$. On the one hand, uncertainty reduces the present value $C_O$ of the product and makes additional investment in the extant technology less attractive. On the other hand, capabilities to process the old material represent platforms for further growth opportunities (Kogut and Kulatilaka, 1994, 2001). The firm holds a growth option on lower cost or improved quality of the old product and on extending its life-cycle (Trigeorgis, 1996). Uncertainty drives the value of the related growth option $G_O$, since uncertain input-cost conditions have an asymmetric effect on expected profits: While the option to substitute materials limits the downside, firms can benefit from favorable cost conditions (Tyagi, 2006). Price uncertainty of the old material increases the variance of the relative prices and, therefore, increases the value of the investment option, which suggests delaying to switch the assets (Kulatilaka and Trigeorgis, 1994; McDonald and Siegel, 1986). An increase in price volatility of the existing input lowers the threshold price for the new input and, therefore, delays the event of optimal switching (Adkins and Paxson, 2011). These previous theoretical findings let us assume that, as soon as the growth option value $G_O$ overrides the negative effect of material price uncertainty $\sigma(p_O)$ on the present value of cash flows, the firm will improve the competitive position by delaying the material substitution.

$H5$: Delaying the market launch under uncertain prices of the old material improves the competitive position.
Models of financial exchange options show that the option to switch loses value by the correlation between two risky asset values (Carr, 1988; Margrabe, 1978). Accordingly, holding a real switching option in new product development is the less valuable, the higher the correlation of their individual values (e.g. Childs, Ott, and Triantis, 1998; Lee and Paxson, 2001; Lint and Pennings, 2002). Previous studies find that decision makers account for correlations of investment outcomes and optimize their portfolio to maximize the switching option value (Belderbos and Zou, 2009; Vassolo et al., 2004). McDonald and Siegel (1986) point to the role of such correlation for the incentive to delay the switch between the alternative assets. A lower correlation increases the value of the investment option and suggests holding the option of switching. A variation in correlation of input-prices changes the boundaries of optimal switching (Adkins and Paxson, 2011). Once a firm has an option to substitute the old product by the new product, a decrease of correlation of the material prices increases the variance of possible outcomes. At the same time, the firm can benefit from positive price developments by a delay, while the downsides are limited. Consequently, the deferral of the switching decision lengthens. Furthermore, the chance that the price development hits the threshold of switching earlier is higher for a correlation of -1 than for perfect correlation (Adkins and Paxson, 2011). In the latter case, holding the switching option is not beneficial to the firm. Based on the sub-additivity component $PE$ in inequality (5), we expect the correlation of material prices $\rho_{NO}$ to positively influence the relation between a delayed product replacement and the competitive position.

\textit{H6: Delaying the market launch under correlated prices of the new and the old material deteriorates the competitive position.}

\textbf{Methods}
Data and Sample

Testing hypotheses on the outcomes of timing market launches 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. To collect information on price developments and competitive moves that are relevant to the delay of distinct material substitution projects, we generated a primary data set by means of a survey. Since material substitutions occur in different industry contexts but bring about similar commercial opportunities (Klevorick, Levin, Nelson, and Winter, 1995), we decided to investigate material substitution projects across industries.

We developed a survey instrument to raise data on material substitution projects. To reduce inconvenience for informants and to increase their willingness to provide information (Huber and Power, 1985), we collected the required information on a seven-point Likert response format. As we ask for objective information such as price developments, we do not need multiple items. The planned and actual dates of starting production of the new product were coded as monthly calendar figures. As such, they help avoid common method bias, which occurs when construct measures are similar (Podsakoff, MacKenzie, Lee, and Podsakoff, 2003). To design the questionnaire, we conducted explorative interviews at industry fairs and conferences. We presented a first draft of the questionnaire to ten industry experts who are familiar with material substitution. We used their feedback to improve the wording, to add items, and to optimize the format. Finally, we discussed the questionnaire 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, we scanned a list of the Association of German Engineers (VDI) and selected 37 networks of firms that are likely to use innovative materials. We contacted the managers of these networks and discussed the relevance of the topic to their member firms. In a second step, we asked the network managers who identified material substitution as a relevant activity to forward the questionnaire to company representatives who are in charge of such projects. Doing so, we increased the probability of identifying persons who are responsible for material substitution projects and are motivated to take part in the survey (Huber and Power, 1985). Among the contacted network managers, 22 agreed on forwarding the questionnaire to members of the network.

We received 129 questionnaires. Among the respondents, 40 percent were CEOs or board members, 35 percent were senior executives, and 25 percent were heads of department or project leaders. We contacted the respondents to provide missing data and to ensure that they are knowledgeable about the project (Kumar, Stern, and Anderson, 1993). We guaranteed anonymity and confidentiality of data handling. 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. Of the remaining projects, 42 were still in the development phase or abandoned before market launch. The final data set embraces 64 completed or delayed material substitution projects of 61 companies. Table 1 presents the sample characteristics.
Table 1

Measurement

Dependent variable. In the survey, we asked respondents to think of one recent material substitution project. To measure competitive position, we use the perceived competitive position after choosing the timing of market introduction. Relative performance measures provide the advantage of comparing projects across industries (Atuahene-Gima and Ko, 2001; Filippini, Salmaso, and Tessarolo, 2004). Furthermore, perceptual measures are associated with secondary objective measures of product innovation (e.g. Zahra and Covin, 1993). We asked the respondents to indicate the acceptance of the sentence “We gained a competitive advantage through the timing of market launch” (1 = strongly disagree to 7 = strongly agree) on a seven-point Likert scale (Calantone and Di Benedetto, 2007).

Independent variables. We asked for the planned date of market launch and the actual date of market launch. The binary independent variable delay holds the value one if the company delayed the market launch, and zero otherwise. 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 environmental uncertainty they perceive (Miller, 1993), earlier real-option studies at the project level use perceptual measures to capture uncertainty (Guiso and Parigi, 1999; Jiang et al., 2009).
Unpredictable fluctuations of the material prices cause uncertainty (Pindyck, 1993). The intensity and occurrence of volatilities of material prices seem to vary over time (WiWo, 2010; Commerzbank, 2012). Respondents were asked to indicate the material price fluctuations (1 = very low to 7 = very high) of the new and the old material before market launch. The variables trendnew and trendold represent the material price trend before the new product was introduced. Respondents were asked to indicate the material price trends ( - 3 = strongly negative to 3 = strongly positive). The variable pricecorr captures the link between the price fluctuations of the alternative materials, indicating the correlation of the expected returns of the underlying assets (Anand et al., 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 variable headstart captures the preemptive effect of new product launch in terms of strategic advantage (Lieberman and Montgomery, 1988). We asked respondents to indicate whether they launched the new product before their strongest competitor on a 7-point scale ( - 3 = much later to 3 = much earlier) (Schilling, 2002).

**Analysis and Results**

Table 2 reveals the descriptive statistics. With the exception of pricecorr and trendnew, respondents used the entire scales to indicate their acceptance of the sentences in the questionnaire. The variable pricecorr was never evaluated as -1, since the prices of substitute materials tend to be positively related in a balance of supply and demand. The pairwise correlation of trendnew and trendold is high and significant. Again, this indicates a relation between materials that are substitutes on the market. The dependent variable and the independent
variables show a reasonable variance. The variance inflation factors (VIF) are low and indicate little problems of multicollinearity.

------------------

Table 2

------------------

Before we run the regressions on the influence of the material price developments on the timing-performance relation, we tested whether the timing decision to launch the new product were directly related to material prices. The results showed that the sample firms, on average, did not seem to consider material price developments systematically when they choose the moment of market launch.

In Table 3, OLS regression models are used to test whether firms improve their competitive positions by delaying market launch as a reaction to material price developments. We start with the base model (Model 1). It shows the simple effects of the variables that moderate the relationship between delay and competitive position: the material price developments (pricecorr, volaold, volanew, trendold, trendnew), the start of production (delay), and competitive preemption (headstart). The variable delay is negatively related to competitive position. Being on the market as planned seems to generally improve the competitive position. It is also generally improved through competitive preemption: the coefficient of headstart is significantly positive.

Model 2 tests whether the interaction of trendnew and delay advances the competitive position. The interaction effect is significantly positive; launching the product with a delay due to increasing prices of the new material trendnew appears to improve the competitive position.
Thus, we find support for H1. Model 3 tests whether the interaction of trendold and delay impairs the competitive position. The interaction effect is negative but insignificant. However, in the full model that includes all price developments of the old and the new material (Model 8), the effect is significantly negative. As all price developments influence the investment rule of inequality (5), we find conditional support for H2. The interaction effect of volanew and delay is tested in Model 4. The effect is significantly positive, supporting H3: delaying the market launch under uncertain prices of the new material volanew enhances the competitive position. A three-way interaction of volanew, headstart, and delay is tested in Model 5. Consistent with H4, the effect is significant and negative. When the firm has a head start before competitors, delaying the market launch under uncertain prices of the new material seems to deteriorate the competitive position. Model 6 tests whether the interaction of volaold and delay improves the competitive position. The interaction effect is significantly positive, supporting H5 that delaying the market launch under uncertain prices of the old material improves the competitive position. Finally, Model 7 tests whether the interaction of material price correlation (pricecorr) and delay affects the competitive position. As the effect is insignificant, we have to reject H6. Delaying the market launch under correlated prices of the new and the old material does not seem to deteriorate the competitive position. All other predicted performance effects of aligning material substitution to the developments of material prices were supported.

------------------

Table 3

------------------
Discussion

The study investigates material price developments under which delaying the launch of a product that is based on a new material and the mutual elimination of the existing product improves the competitive position of the innovating firm. We develop a real-option model and test it on a sample of material substitution projects. The study finds that firms who intentionally or unintentionally choose the timing of new product launch according to material price developments gain competitive advantage. In particular, we find that delaying the market launch under increasing new material prices improves the competitive position, while delaying the market launch under increasing old material prices worsens the position. Theoretically, this insight may not be surprising. However, we tested whether the firms in our sample responded to the price trends and found that they, on average, disregard the trends of material prices. This insight discloses opportunities to improve the competitive position by deliberately choosing the timing of market launch at the back-end of the NPD process. The study also finds that a delay is beneficial under high fluctuations of the new material price. However, when the firm has the chance to preempt competitors, delaying the market launch under new material price uncertainty impairs its position. A delay in the face of old material price uncertainty improves the competitive position.

The study contributes to previous research on the timing of product replacement as a new product introduction strategy (Cohen et al., 1996; Purohit, 1994; Saunders and Jobber, 1988, 1994) by focusing on products that are based on new materials. Research on natural resources shows that uncertainty influences the timing of investment (Brennan and Schwartz, 1985; Cortazar, Schwartz, and Casassus, 2001; Moel and Tufano, 2002; Paddock, Siegel, and Smith, 1988). Tilton (1984, 1991) argues that material substitution decisions are made with respect to
material prices. Surveys confirm that material price changes and material price uncertainties influence the material choice of manufacturing firms (Eastin et al., 2001; Holmes, 1990a, 1990b). Messner (2002) stresses the importance of the old material such that it might delay or even prevent substitution. We show how material price developments of both the new material and the old material influence the innovation success of a delayed material substitution. The results extend previous work that discusses the role of input-cost fluctuations in launch decisions (Tyagi, 2006; Wu et al., 2004) and performance effects of changes in unit costs (Tatikonda and Montoya-Weiss, 2001). Doing so, this article extends earlier work that deals with the role of uncertainty on the timing-performance-relation (Green, Barclay, and Ryans, 1995; Robinson and Min, 2002) by studying the influence of uncertainties on this relation. While previous studies posit that a delay in new product launch reduces innovation performance (Hendricks and Singhal, 1997), this article supports the notion that being on schedule is not always better (Lambert and Slater, 1999) and provide additional arguments why speed as a success factor seems to hold in predictable situations only (Kessler and Bierly, 2002; Meyer and Utterback, 1995). By showing how external contingencies moderate the timing-performance relationship, the study also complements the finding that the interaction of launch timing and internal factors influences new product success (Calantone and DiBenedetto, 2012).

To substantiate the benefits of material substitution under volatile material prices, we use real-option theory (Dixit and Pindyck, 1994; Trigeorgis, 1996). We complement empirical research on firm investment in R&D as real options (Cuervo-Cazurra and Un, 2010; Levitas and Chi, 2010; McGrath and Nerkar, 2004) by a study at the product level. We show that firms improve their competitive position by delaying the market launch when the input-cost factors reduce the value of switching materials and extend theoretical studies that focus on alternative inputs for
flexible production technologies (Kulatilaka, 1986; Kulatilaka and Trigeorgis, 1994). Since material price uncertainties may resolve while the firm waits, a mere focus on speed of innovation suppresses the possibility of leveraging strategic opportunities by an appropriate timing. Altogether, this article supplements empirical studies that highlight the impact of switching options on firm value (Oriani, 2007; Oriani and Sobrero, 2008) and add to the literature that explains performance effects of exercising real options (Reuer and Tong, 2007b). These insights contribute to a combined real-option and resourced-based perspective. Previous work argues that the creation of resource and coordination flexibility makes it possible for NPD managers to plan flexible responses to dynamic environments and subsequently exploit these sources of competitive advantage (Sanchez, 1993, 1995). This study develops arguments on how firms can use flexibility to improve their competitive positions: having the opportunity to produce the new product based on the new material and simultaneously to abandon the old material represents an option to change the use of material processing capabilities. Input-cost developments influence the consequences of resource substitution on the competitive position. Hence, a joint consideration of resource deployment flexibilities, timing flexibilities, and price changes of input factors support the achievement of advantage in product competition.

The study provides important implications for management. Many manufacturing firms are exposed to volatile material prices, e.g. producers of cars who can replace metal parts by plastic parts (Kulatilaka, 1986) or producers of catalytic converters who can switch between platinum and palladium as active agents (Hagelüken, 2005). Our results show that firms who align the timing of material substitution to the development of material prices excel others in competition. NPD managers who strive for accelerating product development by allocating additional resources should keep in mind that the firm may be better off delaying the product launch. This
notion challenges the common wisdom to launch a new product as soon as it is developed (Peres et al., 2010). We rather suggest that NPD managers balance strategic and financial aspects to determine the optimal time of material substitution. NPD investment program managers and procurement managers are to inform the board when the material substitution project value changes and to propose implications for the timing strategy. When material prices suggest a delay, NPD project managers should not be rewarded for keeping to the planned schedule. At the decision gate to market launch, NPD managers can use option values as criteria for transition (Cooper, 2008). While surveys generally show a slow adoption of real-option valuations in practice (Busby and Pitts, 1997; Triantis, 2005; Vollrath, 2003), the acceptance of real-option techniques for new product introductions seems to be relatively high (Block, 2007). This article highlights the importance of both net present values and option values for the timing of material substitutions and provides factors that are useful for quantitative and qualitative analytical instruments. Financial hedging of material prices is possible but not necessary when there is postponement flexibility (Chod, Rudi, and Van Mieghem, 2010). To benefit from price developments, NPD managers need to think proactively about product and process flexibility in design and manufacturing (Sanchez, 1995, 2008). Suppliers of innovative materials can use the insights of this study to promote their products and to convince their customers to adopt a new material early. Suppliers of traditional materials can defend their products by pointing to the volatility of new material prices. Finally, as a policy implication, our results help prioritize activities to support the diffusion of new materials. According to our findings, many firms still seem to launch material substitutions regardless of material price developments.

The study is subject to several limitations. We focus on product replacements and do not regard other types of new product introductions such as line extensions or upgrades (Purohit, 1994;
Saunders and Jobber, 1988, 1994). Even though managers make decisions based on their perceptions of environmental uncertainty (Miller, 1993), a critical point of our methodology is using perceptual measures of uncertainty. Future studies may center 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 our study. With cross-sectional data, we cannot test for causal inferences. Since the study is limited to input cost uncertainties that are typical of material substitutions, future work should examine the influences of other types of uncertainties in specific industries on the timing-performance relationship; our sample is not large enough and does not comprises enough industries to control for industry differences.

The study shows that the optimal timing of market launch is influenced by material-price fluctuations. Since we could not find that all firms consider material price fluctuations at the time of market launch, future studies may analyze the reasons why. Such insights could be valuable for managers to expose constraints and fully leverage the benefits of timing the market launch. Future research should use insights from the timing decision to start developing a product and to launch the new product to enhance our understanding on the relationship between NPD speed and NPD performance (e.g. Chen, Reilly, and Lynn, 2012).
References


### Table 1. Sample Characteristics*

<table>
<thead>
<tr>
<th>Industry</th>
<th>Number of employees</th>
<th>Material substitution path</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive</td>
<td>36%</td>
<td>&lt;50 17%</td>
</tr>
<tr>
<td>Chemicals</td>
<td>16%</td>
<td>50-500 21%</td>
</tr>
<tr>
<td>Mechanical Engineering</td>
<td>14%</td>
<td>501-5.000 31%</td>
</tr>
<tr>
<td>Materials Technology</td>
<td>8%</td>
<td>&gt;5.000 31%</td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>Medical Engineering</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>14%</td>
<td></td>
</tr>
</tbody>
</table>

* N = 64.
## Table 2. Descriptive Statistics and Correlation Matrix

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>competitive position</td>
<td>64</td>
<td>5.30</td>
<td>1.60</td>
<td>1</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>delay</td>
<td>64</td>
<td>0.47</td>
<td>0.50</td>
<td>0</td>
<td>1</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.06</td>
</tr>
<tr>
<td>pricecorr</td>
<td>64</td>
<td>0.15</td>
<td>0.36</td>
<td>-0.6</td>
<td>1</td>
<td>0.01</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.05</td>
</tr>
<tr>
<td>volaold</td>
<td>64</td>
<td>3.88</td>
<td>1.65</td>
<td>1</td>
<td>7</td>
<td>-0.00</td>
<td>0.06</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.12</td>
</tr>
<tr>
<td>volanew</td>
<td>64</td>
<td>3.36</td>
<td>1.46</td>
<td>1</td>
<td>7</td>
<td>-0.10</td>
<td>0.06</td>
<td>0.01</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td>1.21</td>
</tr>
<tr>
<td>trendold</td>
<td>64</td>
<td>0.16</td>
<td>1.17</td>
<td>-3</td>
<td>3</td>
<td>0.06</td>
<td>-0.05</td>
<td>0.27**</td>
<td>0.04</td>
<td>1.00</td>
<td></td>
<td></td>
<td>1.39</td>
</tr>
<tr>
<td>trendnew</td>
<td>64</td>
<td>0.06</td>
<td>0.91</td>
<td>-2</td>
<td>2</td>
<td>0.11</td>
<td>-0.13</td>
<td>-0.04</td>
<td>0.35***</td>
<td>0.42***</td>
<td>1.00</td>
<td></td>
<td>1.54</td>
</tr>
<tr>
<td>headstart</td>
<td>64</td>
<td>0.97</td>
<td>1.69</td>
<td>-3</td>
<td>3</td>
<td>-0.11</td>
<td>-0.13</td>
<td>-0.01</td>
<td>-0.01</td>
<td>0.07</td>
<td>0.09</td>
<td>1.00</td>
<td>1.04</td>
</tr>
</tbody>
</table>

*** p < 0.01; ** p < 0.05; * p < 0.1
Table 3. OLS Regression of Improving the Competitive Position through a Delay of Market Launch

<table>
<thead>
<tr>
<th>Dependent: Competitive position</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
<th>Model 7</th>
<th>Model 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>pricecorr × delay (0/1)</td>
<td>1.2186</td>
<td>1.2035</td>
<td>1.2276</td>
<td>1.1741</td>
<td>1.1580</td>
<td>1.1667</td>
<td>1.2195</td>
<td>1.0793</td>
</tr>
<tr>
<td>volaold × delay (0/1)</td>
<td>0.335</td>
<td>0.331</td>
<td>0.338</td>
<td>0.323</td>
<td>0.328</td>
<td>0.328</td>
<td>0.330</td>
<td>0.314</td>
</tr>
<tr>
<td>volanew × headstart × delay (0/1)</td>
<td>-0.171</td>
<td>-0.207</td>
<td>-0.177</td>
<td>-0.082</td>
<td>-0.062</td>
<td>0.215</td>
<td>0.188</td>
<td>-0.424*</td>
</tr>
<tr>
<td>volanew × delay (0/1)</td>
<td>0.573***</td>
<td>0.583***</td>
<td>0.573***</td>
<td>0.552***</td>
<td>0.489***</td>
<td>0.562***</td>
<td>0.557***</td>
<td>0.433***</td>
</tr>
<tr>
<td>trendold × delay (0/1)</td>
<td>0.206**</td>
<td>0.196**</td>
<td>0.212**</td>
<td>0.200**</td>
<td>0.143*</td>
<td>0.038</td>
<td>0.120**</td>
<td>-0.048</td>
</tr>
<tr>
<td>headstart</td>
<td>0.031</td>
<td>0.069</td>
<td>0.078</td>
<td>0.184</td>
<td>0.177</td>
<td>0.131**</td>
<td>0.050</td>
<td>0.078</td>
</tr>
<tr>
<td>pricecorr</td>
<td>0.510</td>
<td>0.533</td>
<td>0.485</td>
<td>0.308</td>
<td>0.308</td>
<td>0.453</td>
<td>0.088</td>
<td>-0.332</td>
</tr>
<tr>
<td>volaold</td>
<td>0.094</td>
<td>0.092</td>
<td>0.099</td>
<td>0.090</td>
<td>0.091</td>
<td>0.102</td>
<td>0.096</td>
<td>0.075</td>
</tr>
<tr>
<td>volanew</td>
<td>0.097</td>
<td>0.092</td>
<td>0.099</td>
<td>0.144</td>
<td>0.140</td>
<td>0.096</td>
<td>0.104</td>
<td>0.102</td>
</tr>
<tr>
<td>trendold</td>
<td>0.026</td>
<td>0.117</td>
<td>-0.128</td>
<td>-0.049</td>
<td>-0.210</td>
<td>-0.142</td>
<td>0.087</td>
<td>0.124</td>
</tr>
<tr>
<td>trendnew</td>
<td>0.171</td>
<td>-0.207</td>
<td>-0.177</td>
<td>-0.082</td>
<td>-0.062</td>
<td>0.215</td>
<td>0.188</td>
<td>-0.424*</td>
</tr>
<tr>
<td>delay (0/1)</td>
<td>-0.733**</td>
<td>-0.691**</td>
<td>-0.729**</td>
<td>-0.705**</td>
<td>-0.674**</td>
<td>-0.735**</td>
<td>-0.776**</td>
<td>-0.693**</td>
</tr>
<tr>
<td>trendold × delay (0/1)</td>
<td>0.171</td>
<td>0.156</td>
<td>-0.107</td>
<td>-0.117</td>
<td>-0.128</td>
<td>-0.049</td>
<td>-0.210</td>
<td>-0.142</td>
</tr>
<tr>
<td>headstart × delay (0/1)</td>
<td>0.555*</td>
<td>0.573***</td>
<td>0.583***</td>
<td>0.573***</td>
<td>0.552***</td>
<td>0.489***</td>
<td>0.562***</td>
<td>0.557***</td>
</tr>
<tr>
<td>pricecorr × delay (0/1)</td>
<td>0.842</td>
<td>0.857</td>
<td>0.832</td>
<td>0.635</td>
<td>0.627***</td>
<td>0.193</td>
<td>0.693**</td>
<td>0.193</td>
</tr>
<tr>
<td>pricecorr</td>
<td>0.842</td>
<td>0.857</td>
<td>0.832</td>
<td>0.635</td>
<td>0.627***</td>
<td>0.193</td>
<td>0.693**</td>
<td>0.193</td>
</tr>
<tr>
<td>volaold × delay (0/1)</td>
<td>-0.251**</td>
<td>-0.180*</td>
<td>-0.093</td>
<td>-0.193</td>
<td>-0.180*</td>
<td>-0.093</td>
<td>-0.193</td>
<td>-0.180*</td>
</tr>
<tr>
<td>volanew × delay (0/1)</td>
<td>0.489**</td>
<td>0.585***</td>
<td>0.177</td>
<td>0.177</td>
<td>0.177</td>
<td>0.177</td>
<td>0.177</td>
<td>0.177</td>
</tr>
<tr>
<td>F</td>
<td>10.63***</td>
<td>11.87***</td>
<td>9.39***</td>
<td>13.80***</td>
<td>13.42***</td>
<td>9.38***</td>
<td>17.01***</td>
<td>17.01***</td>
</tr>
<tr>
<td>R²</td>
<td>0.4846</td>
<td>0.5063</td>
<td>0.4864</td>
<td>0.5302</td>
<td>0.5678</td>
<td>0.5360</td>
<td>0.4931</td>
<td>0.6535</td>
</tr>
<tr>
<td>Root MSE</td>
<td>1.2186</td>
<td>1.2035</td>
<td>1.2276</td>
<td>1.1741</td>
<td>1.1580</td>
<td>1.1667</td>
<td>1.2195</td>
<td>1.0793</td>
</tr>
<tr>
<td>N</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
</tr>
</tbody>
</table>

Standard errors in parentheses; *** p < 0.01; ** p < 0.05; * p < 0.1
## Appendix. Measures

<table>
<thead>
<tr>
<th>Variables</th>
<th>Operationalization</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent variable:</strong></td>
<td></td>
</tr>
<tr>
<td>competitive position</td>
<td>“We gained a competitive advantage through the timing of market launch” (7-scale: 1 = strongly disagree ; 7 = strongly agree)</td>
</tr>
<tr>
<td><strong>Independent variables:</strong></td>
<td></td>
</tr>
<tr>
<td>volanew</td>
<td>“The price fluctuations of the new material before the market launch were …” (7-scale: 1 = very low ; 7 = very high)</td>
</tr>
<tr>
<td>volaold</td>
<td>„The price fluctuations of the old material before the market launch were …“ (7-scale: 1 = very low; 7 = very high)</td>
</tr>
<tr>
<td>trendnew</td>
<td>“The price trend of the new material before the market launch was…” (7-scale: -3 = strongly negative ; 3 = strongly positive)</td>
</tr>
<tr>
<td>trendold</td>
<td>“The price trend of the old material before the market launch was…” (7-scale: -3 = strongly negative ; 3 = strongly positive)</td>
</tr>
<tr>
<td>pricecorr</td>
<td>„The price developments of the new and the old material were…“ (7-scale: -1,0 = in opposite directions ; 1,0 = in the same direction)</td>
</tr>
<tr>
<td>delay</td>
<td>Dummy variable (1 = company has delayed the market launch; 0 otherwise)</td>
</tr>
<tr>
<td>headstart</td>
<td>“Compared to our strongest competitors, we launched the new product in the market…” (7-scale: -3 = much later ; 3 = much earlier)</td>
</tr>
</tbody>
</table>