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Figures should have titles and explanatory legends containing sufficient details to make the figure easily understandable. Numbers, letters and symbols used have to be sized appropriately. The abscissa and ordinate should be labelled clearly.
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Comments

If you have any comments on articles of the previous issue you are welcome to send them to us as a separate submission. The comments are revised only by an Executive Editor and might be published in the next issue if they suit the academic discussion.

Thank you for your contribution!

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Letter from the Editors

Global Trends – Emerging Challenges for the Chemical Industry

The chemical industry is facing various challenges that derive from global trends such as demographic changes, increasing globalization and urbanization, emerging technologies, or energy and resource scarcity. In order to appropriately respond to such changes in the firm's environment, firms may be forced to exploit and reinforce existing capabilities as well as explore new opportunities to create value. For instance, many chemical companies have strengthened their market positions in fast growing markets such as China or India. Considering the impacts of global trends on the chemical industry, we would like to draw attention to a forthcoming study that is jointly conducted by the University of Muenster and the Provadis School of International Management and Technology. Apart from examining current as well as emerging global trends that concern chemical companies, the study also aims to derive resulting managerial implications. Thus, we are pleased to provide some more detailed insights on this study in our next issues.
With regard to the present issue, we kindly welcome Frank Spiegel and Karl-Martin Schellerer. In their commentary on "Hidden Markets in the Chemical Industry - Illusion or Growth Opportunity?", the authors discuss how chemical companies may make use of existing products while exploring new markets. Here, the authors specifically discuss current trends and fields of application and, thereby, support firms in identifying potential sources of future sales. Furthermore, the authors present success factors for identifying and developing hidden markets.
The research paper of the present issue "Proactive R&D Management and Information Disclosure: Ramifications for Innovative Chemicals Companies" by Tim Swift examines the relationship between R&D expenditure volatility and firm performance in the context of information asymmetry. With R&D expenditure volatility representing a form of information disclosure, the author proposes that investors may place greater emphasis on R&D expenditure volatility under conditions of higher information asymmetry. More specifically, the author outlines the following determinants of corporate opacity as being highly relevant to firm investors: firm's level of R&D intensity, firm age, accuracy of investment analyst earnings forecasts, and bid-ask spread.
The first paper of our Practitioner's Section "Improving R&D productivity requires a balanced approach" by Fang X Zhou and Thomas Bertels uses a case study to illustrate the challenges and characteristics of R&D processes in the pharmaceutical industry that may enhance the firm's productivity. More precisely, the authors suggest to apply a balanced approach by integrating process management with organization's project management capability within a PDCA cycle. Here, the authors emphasize the importance of tailoring these approaches to each companies' unique conditions, particularly regarding process and project management maturity, in order to provide for a current as well as for a long-term productivity improvement in pharmaceutical R&D.
In the article "Bioplastics Tipping Point: drop-in or non-drop-in?", Fabio De Almeida Oroski, Flávia Chaves Alves and José Vitor Bomtempo discuss why non-biodegradable biopolymers, so called drop-ins, have revealed higher growth rates in production capacity than non-drop-in solutions. By comparing the adoption rates of different bioplastics, the authors identify revelant factors that lead to the tipping point of the emerging bioplastics sector. Whereas non-drop-in plastics like polylactic acid are niche products facing several barriers on the demand side, biobased drop-in materials such as polyethylene are well accepted by end users.

Please enjoy reading the first issue of the eleventh volume of the Journal of Business Chemistry. We are grateful for the support of all authors and reviewers for this new issue. If you have any comments or suggestions, please do not hesitate to contact us at contact@businesschemistry.org.

Carsten Gelhard, Executive Editor
(cg@businesschemistry.org)

Birte Golembiewski, Executive Editor
(bg@businesschemistry.org)

Journal of Business Chemistry

Commentary

Hidden Markets in the Chemical Industry - Illusion or Growth Opportunity?

Frank Spiegel*, Karl-Martin Schellerer**

* Dr. Wieselhuber & Partner GmbH Unternehmensberatung, Nymphenburger Str. 21, 80335 Munich, Germany, spiegel@wieselhuber.de

** Dr. Wieselhuber & Partner GmbH Unternehmensberatung, Nymphenburger Str. 21, 80335 Munich, Germany, schellerer@wieselhuber.de

1 Introduction

The chemical-pharmaceutical industry in Germany plays an important role. With its many different products, the industry stands at the beginning of a long supply chain. Over the last number of decades, the high innovation rate has contributed to high growth rates in Germany, even though the market was saturated. The chemical industry in Germany is a driver for technology and innovation – even more so than mechanical engineering. Many downstream branches depend on ideas from the chemical industry, which accounts for 17% of all industry R&D spendings (Kellermann 2012). Besides innovation, the German chemical industry is known for its success abroad. Most firms sell their products in Europe, and often further afield, too. Germany is responsible for 25% of the total sales of chemical products in Europe. In total, more than half of sales are generated abroad (Verband der chemischen Industrie 2013a). To stand out in emerging markets like Asia and South America, risks must be taken into account, especially for small and medium sized firms. It is this kind of firm that is dominating the chemical industry in Germany.

Based on the dynamically changing nature of markets, other sources for growth exist besides innovation and foreign expansion. One can assume that existing products with a formerly defined purpose can also be used in different areas. Ideally no modifications will have to be made to the product. We call these kinds of market opportunities "hidden markets." Product developments that normally require more resources are not the focus of this paper. Most interesting should be these niche markets for firms that supply chemical products to downstream branches outside the chemical industry.

However, the existence of hidden markets in the chemical industry is still doubted and sometimes seen as an illusion. We investigate whether hidden markets are only an illusion or if they really do exist. If we can proof their existence, we want to go on to focus on two questions:

1) What are interesting and upcoming fields where chemical firms could generate additional sales?

2) What are the success factors to develop and exploit hidden markets?

2 The German chemical and pharmaceutical industry in detail

With its large variety of products, the chemical industry can be seen as very heterogeneous. Furthermore, its long supply chain and the fact that it accounts for 11% of total sales of the manufacturing industry in Germany also contribute to this perception. Behind the automotive and mechanical engineering industries, the chemical industry is ranked in third place. One of the strengths of the German chemical industry is the strong partnerships between large multinational enterprises and small firms, along with the fragmentation across basic chemistry (37%), pharmaceuticals (20%) and specialty chemistry (43%). The largest block, specialty chemistry, includes colors, pesticides and plastics, among other things. It is estimated that the focus on specialty chemicals will strengthen in the future. This development is, for example, driven by lightweight construction in the automobile industry (Verband der chemischen Industrie 2013a).

3 A difficult business in the domestic market

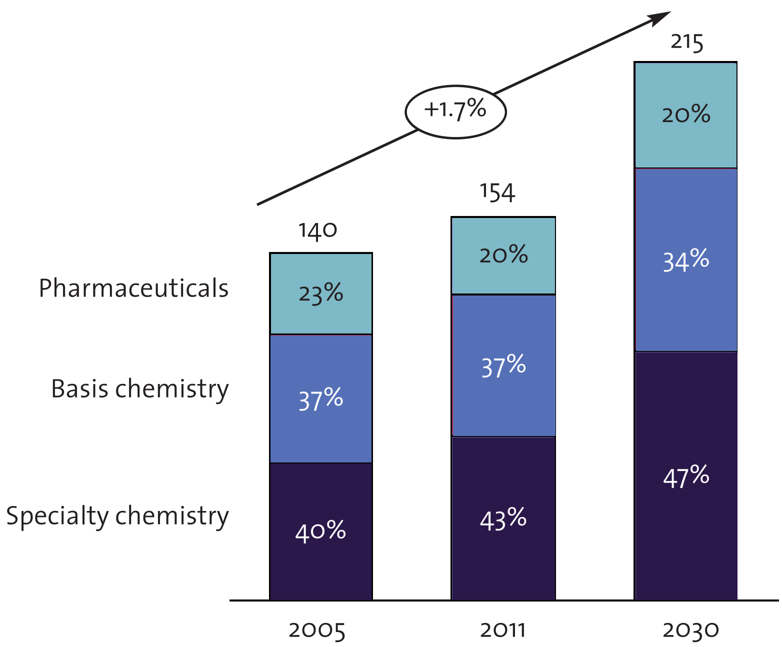
The growth of the chemical industry in Germany has been strongly driven by innovations which have profited downstream industries immensely. Nonetheless, the power of the chemical industry as the driving force for innovations in Germany declined from 1995 to 2005. In 1995, the chemical industry accounted for 20% of interbranch inputs, and in 2005 it was only 15% (Gehrke and Rammer 2011). As a result of the global financial crisis, domestic sales declined and have not yet reached the maximum that had been reached prior to the crisis. While sales rose by 6% in 2011, they dropped by 2.5% in 2012, and by 1% in the first half of 2013. Chemical production in Germany in 2012 is still 3% lower than the pre-crisis level, and not including pharmaceutical production it is still 6% lower (Verband der chemischen Industrie 2013b). If any growth in the domestic market is possible it is estimated to be small and limited. Large, multinational chemistry firms from Germany like Altana, BASF, Evonik and Lanxess all reported declining sales between 3% and 10% for their home market in the first half of the year 2013. This situation is tightened by the rise of raw material prices, so the firms try to compensate the weak results in Germany with their traditionally strong business abroad.

4 Business abroad is risky, too

Strong export business and high sales figures from abroad show the dependency of German chemical firms. In 2013, around 85% of small- and medium-sized firms (with more than 2.5m sales per year) are active abroad. In 2007, the share was only 80% (Commerzbank 2013). Primarily, the firms started their foreign business in Europe. Currently, the situation is not as promising as a few years ago. Economic activity in Europe is weak and its debt crisis is affecting the German chemical industry immensely. The firms also have to expect an unsteady demand in Europe, especially in the southern part of the continent. With time the chemical firms enlarged their efforts step by step into the direction of outside European markets. The strong growth in Asia and South America has justified the focus on business abroad and helped to balance the variations in Germany. But today, growth rates in China are declining and only moderate growth is expected in the USA. In the short- and medium-term, no changes can be anticipated.

However, further risks come along with conducting business abroad. For example, currency risks, the lack of legal security, trade barriers and the protection of intellectual property can be problematic in the context of international sales (Commerzbank 2013). Jürgen Heraeus, Chairman of the Asia-Pacific committee of the German economy, even warns small- and medium-sized firms that they should only make their way to China if enough resources can be raised. Besides capital, time, qualified employees and a strong network are necessary for the development of new customers and markets (Oldenkop 2012).

Figure 1 Growth of the German chemistry production in billion Euro (Verband der chemischen Industrie 2012 and 2013a).



5 The development of hidden markets

German chemistry firms have to face challenges in their domestic as well as in foreign markets. To generate growth, or rather compensate shrinking sales, other methods should be taken into account. Here, the development of so called hidden markets can help. With a systematic approach, additional sales can be generated outside of known branches with existing products and technologies. Maybe the products need to be modified slightly, but expensive developments for new products are avoided. The focus lies on industrial customers outside of the chemistry branch. This development of new markets, e.g. selling existing products to consumers outside of known branches, is called market development (Ansoff 1965).

However, new customers do not necessarily need to come from new branches. It is possible that a product can also be used within the same branch for another application by other customers.

6 Methodology

6.1 Research questions

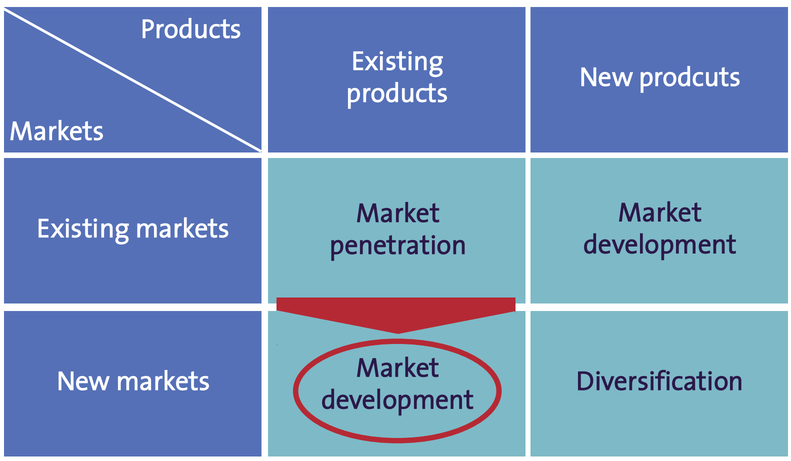
At the beginning, one has to raise the question if hidden markets in the chemical industry really exist or if they are only an illusion. Examples for the use of products in an application field which was not the original purpose can be found from time to time. It is well known that Viagra was originally developed as a medical treatment against cardiac insufficiency. Today it is a blockbuster drug against erectile dysfunctions. However, how firms could identify new fields of application for their existing products and if adequate sales can be generated in these markets has not yet been analyzed. We want to focus on the chemical industry and raise the following questions:

- Have chemistry firms found new fields of application and customers for their existing products?
- What trends affect the chemical industry?
- What fields of application may be of interest to chemistry firms in the future?
- What are critical success factors and requirements for the development of hidden markets?

6.2 Design of the study

The empirical part of the study relies on interviews. We wanted to identify real world examples for the exploitation of hidden markets and the explicit success factors. Outlined topics included the emergence of today's business, possible examples and success factors for the development of hidden markets, as well as current trends that may affect business in the future. Three different groups of interest were contacted. Firstly, decision makers from chemical supply firms, like the CEO or the head of new business development or product management. Secondly, we contacted the CEOs or head of research and development on the customer side. And thirdly, we arranged interviews with experts in the chemical industry or on the customer side from research institutions or consultancy firms. The interviews were conducted personally or via telephone during April and July 2013 and lasted for around 30 minutes.

Figure 2 Ansoff matrix (Ansoff 1965).



6.3 Conducted interviews

In total, 27 interviews were conducted; 11 interviews were carried out with representatives of chemical firms[1] and 11 with customers from outside the chemical industry. The enterprises all have a location in Germany, but are also active internationally. The firms are independent or part of a larger corporate group. The average sales in 2012 were 181m Euro (median) and 840 people were employed on average (median)[2].

6.4 Results

Some interviewees doubted the existence of hidden markets because they had not been successful in generating additional sales in other branches. Consequently, fields of application outside the served markets are not seen as feasible. Furthermore, they believe that if hidden markets exist, only large corporations with enough financial resources and determined divisions focusing on new business development could exploit these niches. But this opinion was only held by the minority of our interview partners. In fact, the existence of hidden markets with a potential for products that were originally designed for other industries was confirmed. Six out of ten chemical suppliers could outline examples in which they developed new markets with existing products, what exactly matches our definition of hidden markets. The stagnation in markets even forces chemistry firms to develop new markets and customers. The difficulty is the lack of information and sometimes the need to modify the business model.

Figure 3 Distribution of interview partners.

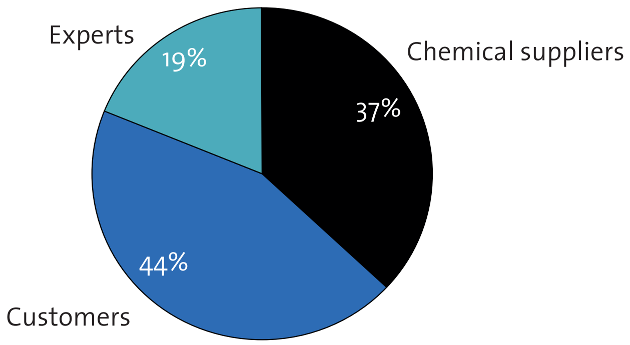
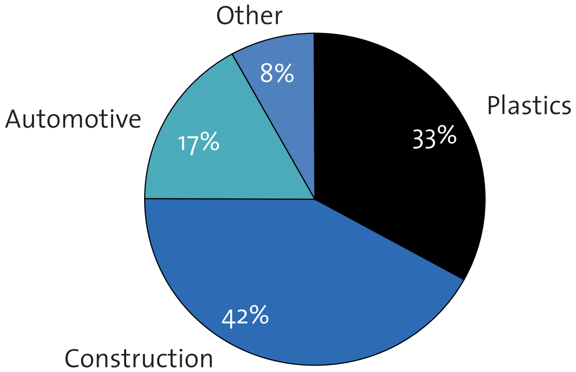


Figure 4 Distribution of the interviewed customers.



1) Two interviews were conducted with one firm.
2) To avoid a shift due to outliers, we report the median.

6.5 Trends which will affect the chemical industry

The chemical industry is a very heterogeneous branch with many different products. Nevertheless, there are trends that affect all players in the industry. Thus, greater trends should be identified in a first step.

For the future an efficient use of resources is becoming more and more important. For example, the chemical industry needs to supply products which help to treat and purify water, and material for better insulation to save energy. Especially the field of renewable energies shows certain potential. Here, solutions that increase the degree of efficiency for wind or solar power plants are very important. Moreover, in order to use today's resources in a more efficient way, abrasion needs to be avoided.

Sustainability was the second most common answer. This includes topics like the protection of the environment, as well as the use of emission and toxic free materials. If the chemical industry can provide solutions for an efficient and sustainable use of resources, large sales can be generated.

Another trend that is seen as important and as a driving force for further growth is the combination of functions, e.g. with only one product results can be achieved where previously two products were needed. This helps to simplify processes and consequently costs are reduced. For example, lubricants that can be used for cooling during the drilling process and at the same time it lubricates the gear are available today. In the past, two different products would have been needed. Many other applications are imaginable. In the last years, many new products have been developed that could substitute previous solutions with completely different approaches, e.g. in mechanical engineering where chemical solutions have not been considered so far. Further trends are the use of nanotechnology, the desire for individualism, lightweight constructions and biocatalysis.

To focus on the most promising ideas for hidden markets, firms should try to establish a link between these trends and their current product portfolio. This helps to concentrate on areas where interesting sales are possible. Otherwise a firm finds a market for its products outside served branches, but the niche is just too small and has no potential.

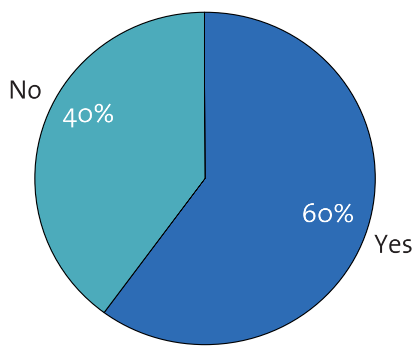
6.6 Future markets for the chemical industry

To develop hidden markets and sell existing products to customers outside served industries, one has to identify these niches. The described trends show a first direction. With these trends a certain dynamic comes along in the chemical industry as well as in downstream branches. With this dynamic, common structures within an industry can be scrutinized and other solutions can substitute current ones. To immerge into more details, fields of application for possible hidden markets are derived. The results are 11 fields that can be clustered into 4 areas: the construction industry, plastics, surfaces and electronics.

The construction industry shows weak growth rates in Europe and Germany. Nevertheless, a new mindset with unconventional solutions offers possibilities.

1) One of the most important materials within the construction industry is concrete that requires cement. Although concrete has a long

Figure 5 Share of chemical supplier firms that have developed hidden markets.



history, radical innovations for concrete have been made. Today, concrete is used in numerous fields including civil engineering and high-building as well as tunnel and bridge constructions. Special concrete is even used for drilling applications. To save resources, the use of alternative materials that exist in large amounts has increased in the manufacturing process of concrete. One of the alternative materials used is blast-furnace slag. In the long run, portland cement will be replaced by other binding materials.

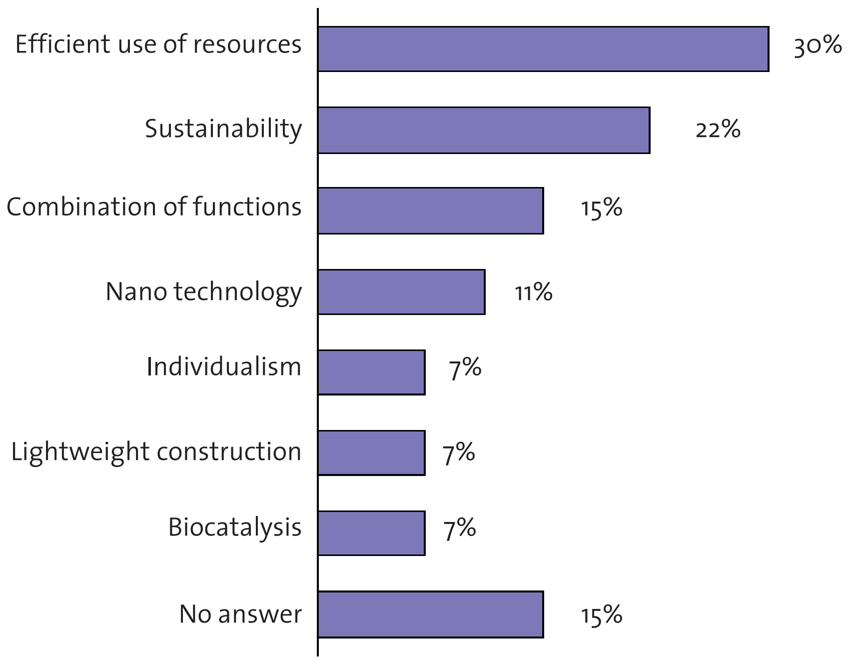
2) To save costly energy for heating and cooling, consumers put more and more emphasis on insulation systems. Solutions that combine an effective insulation into brickwork are favored at the moment. Another requirement is fire-proofing. Current systems that use polystyrene fail mostly on this last point.

3) For the interior fitting, customers place an emphasis on solutions that provide clean and pure air. A photo catalytic approach for the absorption of bad smells or toxic air already exists today and is realized by wall paint. With the help of light, contaminated substances are decomposed into neutral substances. This new kind of wall paint is indeed a product innovation, but it requires common materials like catalysts. The result is not only achievable by using wall paint, but also other construction materials like carpets or wall parts. For a catalyst producer, this application is definitely an interesting opportunity.
Coming to the field of plastics, a sales growth is projected for the global plastics industry, especially in Asia. A high number of different material properties offer a wide range of applications, for example, for components in the automobile industry, in electronics or even in the construction industry. Therefore, plastics can be classified as a reasonable search field for hidden markets.

4) Since lightweight constructions show a high demand, design engineers often use plastics. But plastic does not outperform glass or metal in all ways. That is why engineers expect further improvements in product performance from the plastics industry.

5) Another important topic for the plastics industry is sustainability with the drivers recycling

Figure 6 Trends within the chemicals industry (multiple answers possible).



and bio-plastics. For the latter, one has to differentiate between the functionality, e.g. the plastic is biodegradable, and the raw material basis, e.g. the raw material comes from renewable material. Until 2020, estimations project a share of 20% for bio-plastics from the global plastic production. The most important bio polymers are polylactides (PLA).
Besides the construction and plastics industry, our interview partners classified the field of surfaces as a promising market in the future. Different fields of applications were drafted, in which growing sales can be expected. In each case, functions integrated onto surfaces are becoming more and more important.

6) Coating and painting can be used to reduce moisture and avoid mold. Fields of application include kitchens, swimming pools or boats. Aside from this, normal buildings are also increasingly better insulated, so the natural ventilation that promotes the creation of mold is reduced. To achieve this function today, first products hit the market where nanoparticles are added to paintings.

7) Beside coating and painting, foils are attracting engineers and even end customers. This trend can be noticed on the streets where the original coating of cars is laminated with foils. This protects the coating and is cheaper than recoating the whole car in another color. Apart from aesthetic reasons, functional features can also be realized with foils. They can help to prevent radiation from windows or to store heat in floors. In the field of solar technology, transparent foils could replace expensive panels made out of glass.

8) Combining surface technology with electronics, two interview partners drafted the promising field of conductive coatings. Cables and printed circuits could become obsolete. If these coatings and particles are transparent they could even be applied on displays or other surfaces to achieve completely new features.

9) As the fourth area, electronics as a customer of the chemical industry is forecasted a strong future. Printable switches are an often-discussed topic. However, further research is needed before end products will be available on the market.

10) In addition, the chemical industry must not neglect the large opportunities arising from electrical mobility and solar technology. The performance of batteries has to be improved so that electrical mobility can become interesting for the majority. Firms are working on new battery concepts that provide higher capacities

Figure 7 Possible sources for hidden markets.

Constructions	Plastics	Surfaces	Electronics
1) Replacemet of portland cement by other materials	4) Lightweight construction	6) Coatings to avoid moisture and mold	9) Printable switches and sensors
2) Building bricks with slow-burning insulation	5) Sustainability ■ Recycling ■ Bio-plastics	7) Laminated foils with special features ■ Avoid radiation ■ Store heat	10) Raw materials for new battery concepts ■ Electrical mobility ■ Storage for wind power
3) Photocatalytic products ■ To clean the air ■ To absorb odors ■ To absorb toxic substances		8) Conductive coatings	11) Silicium for photovoltaic (Organic solar cells)

and a growing demand for relevant raw materials supplied by the chemical industry can be expected.

11) Within the photovoltaic field, development goes into the direction of organic solar cells. Their basis is carbon compounds, e.g. plastics. Today the effectiveness of these cells is still too low. But, especially for suppliers of the plastics industry, this field may become very interesting.

The identified future markets illustrate high growth rates for suppliers from the chemical industry.[3] Even if the mentioned applications only represent niches in the beginning, the expected growth can bear an interesting potential for chemical suppliers.

6.7 Successful examples for the development of hidden markets

Until now, we have considered trends and fields of application where growing sales can be expected in the future. Now we want to show, with examples, that chemical firms can indeed develop new businesses outside their served branches.

6.7.1 Example 1: Pigments from the color industry for new functions

The first example comes from a supplier for color pigments that are used in the coating and painting industry. These pigments give a shiny brilliance to the coating because of small particles of metal (like silver, copper or aluminum). These coatings are often used by the automobile industry, especially for the color silver. Since the demand for that color has declined, sales of the pigments have dropped, too. A certain pressure for the pigments manufacturer emerged. Since the demand from other customers also declined, new markets should be developed. The pigments manufacturer followed a technology-push approach since he had the technology and searched for further fields of application. To keep costs low, the focus lies on existing products or technologies, e.g. the effect pigments. And these pigments offer additional features beside the optical one. They are conductive for electrical power and show a high resistance to abrasion. The firm was able to find new customers. The new coating manufacturer was still in the same branch as already served customers. But that firm focused more on coatings with functions instead of on the aesthetics. A completely new customer from a completely new industry was a manufacturer for technical textiles. The pigments are integrated into the clothes to achieve a high resistance of abrasion and heat. This new kind of cloth is used by firefighters, for example. He estimates the sales potential by the hidden markets at around 10% of his current sales.

6.7.2 Example 2: From the construction industry into the tire industry

In our second example, the firm manufactures polycarboxylate ether (PCE) that is used for the production of concrete. The material helps to extract water from liquid concrete, and is also interesting for other products. For example, a tire manufacturer who is today using PCE polymers in his production process was interested. Unfortunately the supplier does not know exactly how his material is being used at the customer's site. This is also the reason why the supplier did not find this hidden market before he was contacted by the tire manufacturer. This is a good example of how an existing product can also be used in a completely different industry.

6.7.3 Example 3: From decking to pencils

The third example was reported by a firm that is manufacturing additives for the plastics industry. In the last few years, the interest for wood plastic composites (WPC) has increased. WPC consists of plastic (PVC) and an organic material like wood dust. A typical application for WPC is decking that was previously made of wood. To supply more additives for WPC, more places where WPC could be used were needed; this is why the supplier started cooperation with a stationary manufacturer, whose pencils had previously been made of wood. The goal of this cooperation was to extrude pencils with the material WPC. Some adaptions for the WPC composition had to be made. The supplier still needs to supply its additives. Beside customers from the plastic industry focusing on decking or other construction materials, he now also supplies a stationary manufacturer. This example shows how a new market was developed where an existing product became obsolete (i.e. wood vs. WPC for pencils). However, sales with additives are now possible not only to the customers extruding deckings, but also with a stationary manufacturer.

6.7.4 Example 4: From gravure to digital printing

Our forth example comes from printing ink branch. In former days our interview partner produced additives and surfactants for ink that have

3) The results are not representative for the whole German industry. That is why additional fields for hidden markets are imaginable.

been used for gravure printing. But the technological development moved further that the digital printing technology made gravure printing obsolete. The firm realized that surfactants are also needed for the ink of laser printers although the printing technologies are totally different. The supplied product is still the same, but only the customers are new.

7 Managerial implications

We now conclude and generalize the success factors to give advice for chemical firms that are interested in the development of hidden markets.

First of all, the overall strategy, in combination with the firm's culture, must make it possible to enter niches and developing markets that lie outside previous branches. The top management must clearly communicate the needs and goals when searching for hidden markets. Employees must understand the potential of hidden markets and their exploitation can be easier than new product development or selling products in foreign countries.

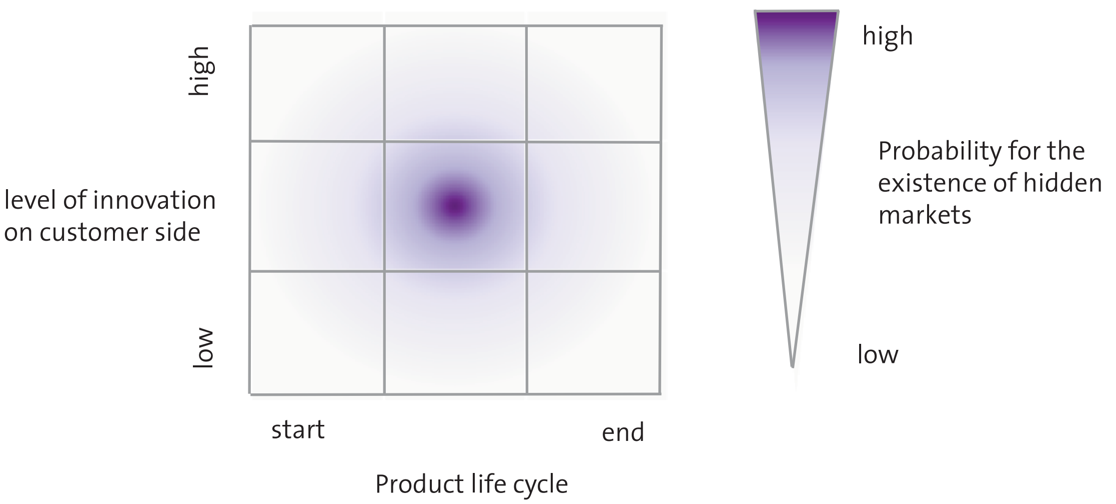
In the above case, two approaches were followed. 1) Market-pull implies a problem that exists on the customer's side, and a supplier that already has an adequate solution, only needs to identify this need. 2) Technology-push means that a customer does not have an urgent need, but gets convinced by the supplier since the product performance is superior. Hence, the supplier substitutes other solutions. Our interviews show that the market-pull approach is more promising, since the customer really needs to solve a problem.

One of the big challenges for developing hidden markets is the lack of information. To be successful, it is necessary to have extensive knowledge of the markets. The chemical firm needs to understand the structure of suppliers and the products of competitors – even outside their known branches. Especially for products or technologies that should be pushed into a new market, it helps to analyze the supply chain. One needs to know how the own product can be used and how it affects parts further down the supply chain. The desire of the end customer can help the supplier to convince a customer by his product.

As soon as a hidden market is identified and one thinks about how to enter this market with the existing product, it is important to focus on the own core competencies. The goal is to sell existing products to new customers and not to modify the whole business model. It is difficult enough to establish a relationship to new customers from unknown industries. However, smaller adaptions to the business model might be necessary if a new branch with new competitors is developed.

Another important success factor for entering a new market is cooperations. The partners can profit from each other's know-how and ideally the partner becomes your first customer.

Figure 8 Evaluation of search fields for hidden markets.



The development of hidden markets is not only for large firms as suspected. As shown before, there are also enough niches for small- and medium-sized firms. The trick is to have a structured process that fits to the size of the firm. This can be done by only one person or by a large team in the business development unit. However, it is important that trend analyses and the search for possible new markets are not a part-time job, but rather a full-time job. While screening the trends many firms focus on their current business, i.e. their core and nearby fields. More successful firms are able to abstract their competencies and link them to superior mega trends. Since these affect our whole society and the chemical industry stands with many products at the beginning of the supply chain, significant changes can be expected by globalization, urbanization or climate change (Schellerer 2013).

After the identification of dedicated search fields and initial ideas regarding where existing products could generate additional sales, a stage-gate process helps to use resources efficiently (Cooper 1994). At each gate, one has to decide if it is feasible to carry on the project. Here it is interesting to know that only a small share of ideas will in the end generate some sales.

To successfully find new customers for existing products, it should be considered that most customers expect solutions. Chemical suppliers need to offer more than capsuled products or technologies, where the customers must think about the possible application. The supplier must be able to show the advantages of his product and how his product works within the ecosystem of the customer.

Finally, we want to answer the question where hidden markets are most likely to be found. We see the largest potential for products in the middle of their life cycle and with a medium level of innovation on the customer side. New products should be introduced for established customers. For old products it is unlikely that an unknown use can be identified. On the customer side, radical innovations normally require new products with a high inventive step. If the customer focuses on incremental innovation, process improvements and cost cutting aspects are pursued. There, chemical suppliers might identify hidden markets, but the probability is lower than focusing on customers with a medium innovative portfolio (Schellerer 2013).

8 Final comment

So far, hidden markets were often seen as an illusion and if they were identified, this “secrecy” was not revealed.

In this fascinating context, we focused on hidden markets and their existence in the chemical industry. We finally conclude with the following statements:

1. Hidden markets do exist within the chemical industry, however, not everywhere.

2. Hidden markets are most likely to exploit where products on the customer side are in the middle of their life cycle and where the level of innovation shows a medium level.

3. Hidden markets offer a sales potential of 10 percent on average.

4. The reasons that some firms already have exploited hidden markets and others not can be found within the firms not on the markets.

5. The success rate relies on the culture and organization of the firms.

6. Customers of the chemical industry must not rely on suppliers with their ability to find hidden markets. An interdependent understanding and open communications is necessary.

References

Ansoff, H. (1965): Checklist for Competitive and Competence Profiles, *Corporate Strategy*, pp. 98-99, New York, McGraw-Hill.

Braun, M., Teichert, O. and Zweck, A. (2006): Biokatalyse in der industriellen Produktion – Fakten und Potenziale zur weißen Biotechnologie, *Zukünftige Technologien Nr. 57*, Zukünftige Technologien Consulting der VDI-Technologiezentrum GmbH (Eds) (Düsseldorf).

Commerzbank (2013): Neue Märkte, neue Chancen – Wachstumsmotor Internationalisierung. *13. Studie der UnternehmerPerspektiven* (Frankfurt am Main).

Cooper, R. G. (1994): Perspective third-generation new product processes, *Journal of Product Innovation Management* **11**(1), pp. 3-14.

Gehrke, B. and Rammer, C. (2011): *Innovationsindikatoren Chemie 2011*, Zentrum für Europäische Wirtschaftsforschung (Mannheim) und Niedersächsisches Institut für Wirtschaftsforschung (Hannover).

Germany Trade and Invest (2012): Deutscher Kunststoffmarkt wächst in schwierigem Umfeld, available at http://www.gtai.de/GTAI/Navigation/DE/Trade/maerkte,did=689758.html, accessed 09 August2013.

Kellermann, C. (2012): *Branchenporträt der deutschen* *chemisch-pharmazeutischen Industrie 2012*, Verband der chemischen Industrie (Frankfurt am Main).

Oldenkop, A. (2012) *Wie Mittelständler in China Erfolg haben*, Wirtschaftswoche, available at http://www.wiwo.de/unternehmen/mittelstand/hannovermesse/neu-in-china-wie-mittelstaendler-in-china-erfolg-haben-seite-all/6557988-all.html, accessed 09 August 2013.

Plastics Europe: *Kunststoff-Verwertung*, available at http://www.plasticseurope.de/das-ist-kunststoff/verwertung.aspx, accessed on 09 August 2013.

Rammer, C., Sofka, W., Legler, H., Gehrke, B. and Krawczyk, O. (2009): *Innovationsmotor Chemie 2009 – FuE-Potenziale und Standortwettbewerb*, Zentrum für Europäische Wirtschaftsforschung (Mannheim) und Niedersächsisches Institut für Wirtschaftsforschung (Hannover).

Schellerer, K.-M. (2013) *Versteckte Märkte in der Chemie*, CHEManger; available at http://www.chemanager- online.com/themen /chemikalien-distribution/studie-versteckte-maerkte-der-chemieindustrie, accessed on 17 October 2013.

Verband der chemischen Industrie (2013a): *Die deutsche chemische Industrie 2030* (Frankfurt am Main).

Verband der chemischen Industrie (2013b): *Die Zukunft gewinnen mit einer starken Chemie*, available at https://www.vci.de/Presse/Pressemitteilungen/Seiten/Die-Zukunft-gewinnen-mit-einer-starken-Chemie--VCI-Pressekonferenz-zum-ersten-Halbjahr-2013.aspx, accessed on 09 August 2013.

Verband der chemischen Industrie (2012): *Chemiewirtschaft in Zahlen 2012* (Frankfurt am Main).

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Research Paper

Proactive R&D Management and Information Disclosure: Ramifications for Innovative Chemicals Companies

Tim Swift*

* St. Joseph's University, Management Department, 5600 City Avenue, Philadelphia, PA 19131, tim.swift@sju.ed

A common view is that investors view steady firm-level R&D investment as evidence of the firm's commitment to R&D-based innovation. However, recent research shows that R&D expenditure volatility is positively related to firm performance, suggesting that higher levels of R&D expenditure volatility indicate effective governance of the R&D function. This paper shows that the relationship between R&D expenditure volatility and firm performance is stronger within firms that have higher levels of information asymmetry between the firm and its investors. This finding suggests that investors interpret R&D expenditure volatility as a good thing, and that this form of information takes on more significance in the absence of better sources of evidence. Innovative chemicals companies may reconsider conventional wisdom suggesting that consistent R&D expenditure conveys an emphasis on R&D-based innovation. Instead, firms can explain to investors that significant changes in R&D expenditure indicate that management is proactively managing R&D projects and combating R&D overinvestment.

1 Introduction

A recent report by McKinsey and Company shows that, in general, innovation in the chemicals industry continues to generate returns well above the cost of capital, but that a high degree of variation exists in innovation performance. The authors observe that while attractive opportunity exists within the industry, some firms fail to structure their R&D properly (Meremadi et al., 2013). Particularly within the chemicals industry, firms must develop innovation processes that drive the creation of valuable scientific knowledge.

Innovative firms must do two things well. They must exploit their existing competencies in order to create value for firm stakeholders. They must also explore for new forms of advantage so that they can remain competitive as markets shift to new a new paradigm, which makes prior forms of innovation obsolete (March, 1991; 1996; 2006). This exploration/ exploitation tradeoff is particularly important in R&D-intensive industries, where the value of older forms of R&D-based innovation are constantly eroded by competitive imitation and newer, superior forms of innovation.

A common view is that firms investing consistently in R&D over time to create the least amount of disruption in their R&D labs. Consequently, they make the steadiest progress towards valuable innovations. In fact, previous research tells us that consistent, steady R&D investment is required in order to create sustainable competitive advantage (Dierckx and Cool, 1989), and that "research workers are not perfectly elastic in supply and cannot be fired and rehired as business conditions might warrant" (Hambrick *et al.*, 1983: 759). This literature suggests that firms change R&D expenditure for reasons that could seriously impact progress towards innovation.

However, an alternative view is possible. Firms that invest about the same amount in R&D over time may be suffering from organizational inertia (Hannan and Freeman, 1984) that prevents them from making adjustments to the firm's innovation processes. This suggestion implies that stable R&D investments over time arise from bureaucratic inaction, making timely and necessary changes to the firm's R&D function difficult to implement.

In fact, research has shown that R&D expenditure volatility can arise under many contingencies. Some of these contingencies are beneficial to sustained firm performance; others are not. Firms reduce R&D expenditure in order to improve short-term earnings performance (Baber *et al.*, 1991; Dechow and Sloan, 1991), which could erode the firm's long-term innovative capabilities. Firms modify R&D expenditure based upon the level of technological and market uncertainty they face (Oriani and Sobrero, 2008; Levitas and Chi, 2010).

While narrow contingencies exist within which changes in R&D expenditure can be harmful to firm performance (e.g. – earnings manipulation), recent research indicates that, in general, fluctuations in firm-level R&D expending is a good thing. R&D expenditure volatility is positively associated with firm growth (Mudambi and Swift, 2011). Recently, Mudambi and Swift (2013) find that higher levels of compact, significant changes in R&D expenditure indicate that the firm is moving between R&D-based exploration and exploitation. Increases in R&D expenditure above the firm's historic trend are associated with increased exploratory R&D and the creation of highly cited patents; dramatic changes in R&D spending in either direction are associated with higher firm valuations and higher levels of patented firm knowledge.

Business academicians have been criticized for conducting research that has little impact on real-world issues (Bailey and Ford, 1996; Pfeffer and Fong, 2002). Do these findings about the relationship between R&D expenditure volatility and firm performance really matter? It is important to evaluate not only the theoretical, but also the practical significance of this emerging area of study.

The purpose of this paper is to determine whether R&D expenditure volatility is important to investors. If higher levels of R&D expenditure volatility indicate that executive managers are proactively monitoring the firm's R&D function, then investors may infer that this volatility is evidence that the firm is combating R&D management entrenchment that can lead to the decline of the firm's competitive advantage. This new research on R&D expenditure volatility can be linked to prior work on firm valuation under conditions of information asymmetry between the firm and its investors in order to glean new insights on the meaning and importance of R&D expenditure volatility to the investment community.

The level of information that the firm provides to external investors is an important driver of firm value. Firms disclose information through a variety of means such as compulsory filings with government agencies, press releases, quarterly results briefings, annual shareholders' meetings, and private communications with important market analysts. Firms that provide higher levels of information have lower levels of information asymmetry between firm insiders and outside investors; such firms are considered to be transparent. This high information disclosure increases investor confidence that the firm mitigates agency problems and generally results in higher firm valuations (Clarkson et al., 1996; Easley and O'Hara, 2004).

Firms that disclose less information have higher levels of information asymmetry, and can be characterized as opaque. Opaque firms provide less information to outside investors; this lack of information increases the likelihood that inside investors such as founding family members can exploit minority investors, leading to poorer firm performance (Easley and O'Hara, 2004; Anderson *et al.*, 2009).

Information asymmetry is influenced by several factors. Prior research shows that younger firms (Berger and Udell, 1995) and firms with higher levels of R&D intensity (Aboody and Lev, 2000) are less transparent to investors. In other words, under these conditions, less information is available to outside investors; therefore it is more difficult for firms to evaluate accurately the performance of the firm.

Under conditions of higher information asymmetry, investors place greater emphasis on secondary sources of information, such as top management team demographics (Sanders and Boivie, 2004: 168). For example, secondary sources of information have been found to be particularly important to firm valuation in firms with higher levels of R&D intensity since it is difficult for firm outsiders to observe progress in R&D (Gu and Li, 2007). Thus, if investors view R&D expenditure volatility as a form of information disclosure, then these expenditure patterns should have a stronger influence on firm value among firms with higher levels of information asymmetry.

In this paper, I show that, in general, investors consider volatile R&D expenditure a good thing. I accomplish this task by showing that the relationship between R&D expenditure volatility and firm value is stronger when investors have relatively less information with which to evaluate the firm. Using financial and economic data from 3,074 publicly traded manufacturing firms comprising almost 17,000 firm-year observations from 1997 to 2006, I find that the relationship between R&D expenditure volatility and firm value is stronger under conditions of higher corporate opacity (i.e.: higher information asymmetry). Sub-sample analysis on observations from firms participating in the chemicals industry reveals similar results. This finding implies that when investors have relatively less information with which to evaluate firm prospects,

they place greater emphasis on R&D expenditure volatility as an indication that the firm is proactively managing its R&D function properly.
This news has important practical ramifications. Since prior research suggests that consistent, steady R&D investment over time is the best path to creating firm value (Dierckx and Cool, 1989), firm managers can be impelled to maintain consistent R&D expenditure over time, in the hope that this steady expenditure profile indicates to outside observers that the firm is committed to investing patiently in R&D, without pressing for unrealistic results. However, if investors consider firm level R&D expenditure volatility as a sign of proactive R&D management, firm decision-makers may permit R&D expenditure to fluctuate, and to communicate the reasons for these changes to the investment community.

2 R&D expenditure volatility and information asymmetry: Research hypotheses

It is possible to interpret the meaning of R&D expenditure volatility in multiple ways. Reductions in R&D spending have long been interpreted as earnings manipulation, wherein firms reduce R&D spending in order to generate short-term earnings improvement. Prior research has documented two circumstances under which firms reduce their level of R&D expenditure in a manner consistent with this view. R&D spending is more likely to be reduced when the CEO approaches retirement (Dechow and Sloan, 1991) or when the firm is likely to miss an earnings objective (Baber *et al.*, 1991; Perry and Grinacker, 1994).

Firms that consistently increase R&D spending may be viewed as having volatile R&D spending. However, firms often overinvest in R&D (Barnet and Freeman, 2001; McMath and Forbes, 1998; Demirel and Mazzucato, 2012). A steady, relatively linear increase in R&D spending may indicate R&D overspending, wherein firms are unable to cull underperforming R&D projects. Conversely, firms that persistently decrease R&D spending are likely to be in significant decline (Chen and Miller, 2007).

However, firms that both increase and decrease R&D spending over time have been shown to be superior firms. A broad body of findings suggest that exploratory R&D is more expensive than exploitative (Clark et al., 1987; Clark and Fujimoto, 1991; Dyer, 1996; DiMasi *et al.*, 2003; Gagnon and Lexchin, 2008; Harryson *et al.*, 2008). Compact, relatively large increases in R&D spending are associated with increases in exploratory R&D and the creation of more highly cited patents (Mudambi and Swift, 2013). In turn, decreases are associated with increases in exploitative R&D. Firms with higher levels of overall R&D expenditure volatility exhibit higher levels of firm growth (Mudambi and Swift, 2011) and superior firm valuation (Swift, 2013).

Taken collectively, this new research suggests that the best firms have the ability to proactively manage their R&D portfolios, transitioning from exploitative R&D to exploration once the value of the firm's R&D portfolio wanes, and back to exploitation once the firm finds new sources of competitive advantage (Mudambi and Swift, 2011; Mudambi and Swift, 2013). This form of R&D management, wherein the firm moves between periods of exploration and exploitation, results in a volatile R&D expenditure pattern over time.

In addition to the well-known challenges related to the tradeoffs between exploration and exploitation (March, 1991; 1996; 2006), innovative firms must deal with the problems related to information asymmetry. Accounting information for R&D-intensive firms is less informative than for low (or non) R&D firms. Aboody and Lev (2000) offer three reasons for this. First, since R&D expenditures are expensed immediately, the knowledge assets created by R&D are not recorded on the firm's balance sheet. Investors cannot evaluate the effectiveness of the firm's R&D investments in the short run by observing changes in the balance sheet. Second, since R&D projects are unique to the developing firm, investors cannot compare one firm's R&D expenditures to R&D expenditure of comparable firms. Third, since no open market exists for R&D-based knowledge, the market does not inform us on the value of a particular firm's R&D output by assigning a price to it. Investors do not receive guidance from the market on valuing the R&D outputs of a particular firm. As a result, it is likely that greater information asymmetry exists between the R&D-intensive firm and its investors.

Not only is information asymmetry higher between the R&D-intensive firm and its investors, but also greater efforts are made by R&D-intensive firms to mitigate that information asymmetry. Tasker (1998a) shows that the number of conference calls conducted with investment analysts is higher in R&D intensive firms, and that the majority of questions raised by analysts on these calls are related to the firm's R&D (1998b). Higher R&D intensity increases firm opacity, and also increases the importance of the firm's R&D function to investors. De facto, since R&D is a major form of investment for R&D-intensive firms, investors place greater emphasis on the importance of R&D spending in these firms.

There are several drivers of the level of information asymmetry between the firm and its investors. In general, research indicates that higher levels of R&D intensity (Tasker, 1998a; Tasker, 1998b; Aboody and Lev, 2000) and relatively recent initial public offerings (Burger and Udell, 1995) can increase firm opacity. In addition, reduced information disclosure leads to higher information asymmetry, and decreases firm value (Clarkson *et al.*, 1996; Easley and O'Hara, 2004).

Figure one below represents my research question. In this paper, I evaluate whether the level of information asymmetry between the firm and its investors influences the relationship between R&D expenditure volatility and firm value.

Prior research has established the positive relationship between R&D expenditure volatility and firm performance (Mudambi and Swift 2011; 2013; Swift, 2013) as well as the negative relationship between information asymmetry and firm performance (Easley and O'Hara, 2004). The research focus in this paper is on the moderating role of information asymmetry on the relationship between R&D expenditure volatility and firm performance. I proceed to evaluate my research question using two important determinants of firm opacity: the intangible nature of firm capabilities; and reduced information disclosure.

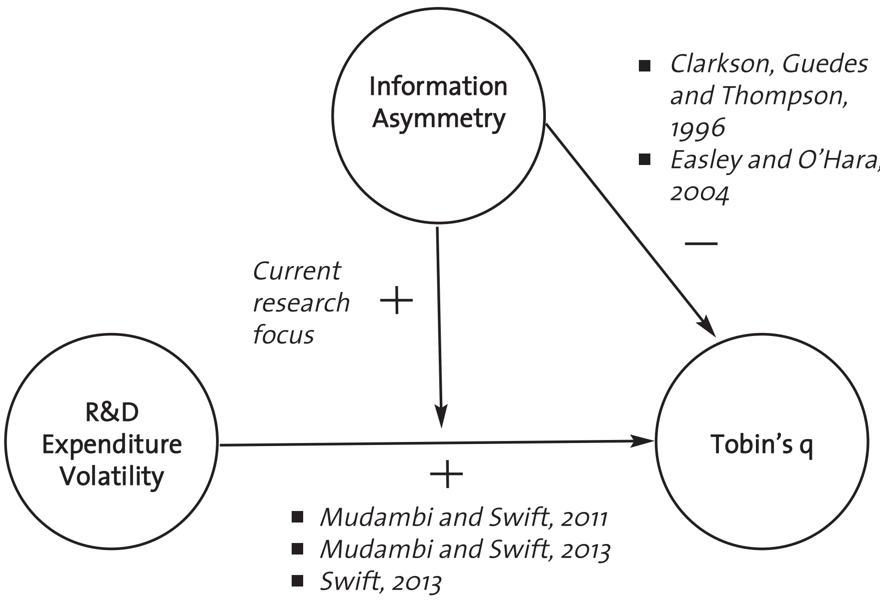
2.1 R&D Expenditure Volatility and Intangible Capabilities

In the preceding section, I noted that prior research has found that higher levels of information asymmetry decrease firm value. However, firms may possess intangible capabilities that can both increase firm opacity and firm value. For example, R&D-based innovation is difficult for outside investors to observe. This type of intangible capability increases information asymmetry (Aboody and Lev, 2000). As a result, outside investors demand higher investment returns in order to compensate for the risk of this information asymmetry (Riley, 1989). This demand for higher returns decreases firm value by increasing the firm's cost of capital. Yet R&D-based innovation also creates many forms of valuable innovation, simultaneously increasing firm value (Hall *et al.*, 2005). In general, the net direct impact of many forms of intangible capability on firm value is positive. The first set of hypotheses test the effect that the level of firm intangible capabilities has on the relationship between R&D expenditure volatility and firm value.

2.2 Corporate opacity and R&D intensity

As mentioned above, the level of firm opacity can be exacerbated within highly innovative firms, because opacity is particularly problematic in R&D-intensive firms (Tasker, 1998a; Tasker 1998b; Aboody and Lev, 2000). R&D project payoffs are difficult to anticipate; R&D projects can persist for 10 to 12

Figure 1 Conceptual Model.



years without producing a rent-generating patent (Bernardo *et al.*, 2001). Even if R&D projects do pay off, the benefit to the firm may be difficult to observe. Many firms devote R&D investment to creating process innovations that are not patented (Devinney, 1993) and do not produce results that are readily observable to the investment community.

The combined forces of higher levels of information asymmetry and the heightened importance of R&D spending to the firm should prompt investors to place greater emphasis on the meaning of R&D expenditure volatility. This logic leads to a first hypothesis.

H1: The positive relationship between R&D expenditure volatility and firm value is stronger among firms with higher levels of R&D intensity.

2.3 R&D expenditure volatility and firm age

In general, firm age is negatively related with firm value. Older, larger firms are less likely to search for new knowledge and information (March, 1988; Miller and Chen, 1996). In addition, older firms have more standardized procedures, which can reduce organizational flexibility (Hannan and Freeman, 1984; Nystrom and Starbuck, 1984). Younger firms are also smaller. Thus it is more likely that these smaller firms can post higher percentage rates of growth, which are likely to increase firm value (Hayashi and Inoue, 1991; Lang *et al.*, 1996).

Firm age is an important determinant of firm opacity (Berger and Udell, 1995). Entrepreneurs in smaller firms often have highly specialized skills, and can be overwhelmed with the administrative tasks involved with managing a complex firm (Ciampi and Gordini, 2009). Thus management in smaller, younger firms is less able to engage in investor relations, which can decrease information asymmetry. Investors learn about firms over time. Younger firms have had less time to inform investors on their future prospects, to build a reputation, or to demonstrate stable and predictable performance. Prior research shows that lenders demand higher rates of return from young firms in initial periods, and lower rates in subsequent periods after lenders have learned more about firm prospects (Boot and Thakor, 1994). Firm youth increases the information asymmetry between the firm and the investment community.

Building firm-level legitimacy is a path-dependent process. By meeting performance targets and keeping commitments, firms gain the trust of stakeholders. Firms cannot acquire this credibility quickly; reputation is built over time. *Ceteris paribus*, investors are less able to observe the firm's R&D function accurately within younger firms. Thus, investors in younger firms have less information with which to evaluate the firm's R&D prospects, and should rely more on the meaning of R&D expenditure volatility. These observations lead to a second research hypothesis.

H2: The positive relationship between R&D expenditure volatility and firm value is stronger among younger firms.

2.4 R&D expenditure volatility and reduced information disclosure

Innovative firms have good reason to withhold information from its investors. Perhaps the best reason that firms focusing on innovation may minimize information available to the public is the "Arrow paradox" (Arrow, 1962), which occurs when firms attempt to move intellectual property across firm boundaries. Buyers of innovation demand information about it in order to evaluate their purchasing decision. However, in the process of disclosing this information, the seller effectively transfers this innovation to the buying firm without receiving any compensation. Thus, it pays for innovative firms not to disclose too much information about its proprietary knowledge, which drives up information asymmetry between the firm and its stakeholders.

Within these opaque firms, insiders hold more information than the investment community at large. Outside investors can be exploited by inside investors that have superior information. "This cross-sectional effect results in the uninformed traders always holding too much of stocks with bad news, and too little of stocks with good news" (Easley and O'Hara, 2004: 1554). Two ways to measure the amount and quality of information that is available to investors is the accuracy of investment analyst earnings forecasts, and the bid-ask spread on the firm's share price. The bid-ask spread is the difference between the highest price that a buyer is willing to pay for a share of firm stock and the lowest price at which a seller will sell the share. This difference is kept by the equity exchange specialist handling this transaction.

2.4.1 Corporate opacity and analyst earnings estimates

Higher amounts of information reduce the difficulty of estimating the true value of the firm's assets (Clarkson *et al.*, 1996; Easley and O'Hara, 2004). This research provides strong evidence that more information reduces the cost of equity capital through reduced estimation risk.

One way to evaluate the information that is available on a firm is to observe the accuracy of analyst earnings forecasts. Professional investment analysts gather information on firms via public and private sources by doing things such as scrutinizing the firm's public information disclosures and evaluating insider trades (Healy and Palepu, 2001). The accuracy of stock analyst earnings forecasts are a function of the quality of information that the firm makes available to the investment community (Barron *et al.*, 1998).

Among firms with higher analyst earnings forecast errors, investors have less information with which to evaluate the firm's prospects. Thus, investors place greater reliance on secondary performance indicators such as R&D expenditure volatility. This observation leads to a third research hypothesis:

H3a: The relationship between R&D expenditure volatility and firm value is stronger among firms with higher analyst forecast earnings error.

2.4.2 Corporate opacity and bid-ask spread

Higher levels of information asymmetry between the firm and its investors also increase the level of risk incurred by market markets on equity exchanges (Diamond and Verrecchia, 1991). When a dearth of information exists on publicly traded firms, investors are less able to accurately assess the true value of the firm. For example, prior work has found that when the market maker perceives that the information advantage held by informed investors has increased, market makers increase the bid-ask spread in order to accommodate the increased trading risk (Copeland and Galai, 1983; Glosten and Milgrom, 1985). Other work shows that information events such as earnings and dividend announcements impact the bid-ask spread (Venkatesh and Chiang, 1986). Under conditions in which market makers are less able to evaluate the true value of the firm, investors place greater emphasis on the meaning of R&D expenditure volatility. This line of reasoning leads to a final, complementary hypothesis:

H3b: The relationship between R&D expenditure volatility and firm value is stronger among firms with higher bid-ask spreads.

3 Research Methods

3.1 The Data

The sample frame is generated from the Compustat Annual North America databases (Standard and Poors, 2011) which provide accounting and market information on all publicly traded firms in the U.S, the Center for Research in Security Prices (CRSP) database (CRSP, 2011), which provides bid and ask prices publicly traded stocks, and from the Institutional Brokers' Estimate System, or I/B/E/S (Thomson-Reuters, 2011), which provides institutional analysts' earnings forecasts over time. I constructed two data sets to test my hypotheses. Since fewer firms have an analyst following, the dataset used to test information asymmetry is smaller than the dataset used to test intangible assets. In order to test the hypotheses using information asymmetry as measured by bid-ask spread or analyst earnings forecast accuracy, I include only those firms that report bid-ask spread data in CRSP, and analyst forecasts in I/B/E/S.

A measure of industry concentration is taken from the U.S. Economic Census (U.S. Census Bureau, 2002). Following Hall *et al.* (2005), all manufacturing firms (NAICS codes 31 through 3399) are selected. Each observation represents one firm-year. After removing observations with missing values, the data set used to evaluate information asymmetry contains 6,373 firm-year observations. The dataset used to evaluate the influence of intangible firm capabilities contains 17,016 firm-year observations. Since not all firms existed for each year of the ten year study window selected, this is an unbalanced panel. The average number of years reported for each firm is 5.5 years.

This data set covers the years 1997 to 2006. Periods of punctuated change within the punctuated equilibrium model have been shown to be fairly compact. Romanelli and Tushman (1994) showed that most firms accomplish profound change within two years. Thus, over the ten year study window used in this paper, good chance of observing periods of punctuated change exists.

3.2 Dependent variable

Tobin's q Firm value is measured using a proxy for Tobin's q. Tobin's q is defined as the ratio of the market value of a firm to the replacement cost of its assets. Firms with a q-ratio greater than unity are creating economic value. Q incorporates a capital market measure of firm rents, minimizes distortions due to tax laws and accounting conventions, and implicitly uses the correct risk-adjusted discount rate (Wernerfelt and Montgomery, 1988).

For the purposes of this analysis, Chung and Pruitt's (1994) simple approximation of Tobin's q is used. It retains almost all of the original informativeness of the theoretically correct q ratio. Their approximate q implicitly assumes that the replacement values of a firm's plant, property and equipment (PP&E) and inventories are equal to their book values. The market-value of debt is substituted by the value of the firm's short-term liabilities less the short-term assets plus the book value of the firm's long-term debt. The authors find that at least 96.6% of the variation in Tobin's q is explained by the approximate q.

3.3 Independent variables

The following variables are included in the regression analysis in order to evaluate the research hypotheses offered above.

3.3.1 R&D Expenditure Volatility

R&D expenditure volatility can be an observable marker for successful proactive management. I measured it over the ten year study period as the standard deviation of the residuals from the firm's R&D expenditure trend over the study period (Mudambi and Swift, 2011; Swift, 2013). This measures R&D volatility net of R&D expenditure growth. The calculation is performed using a two-step process. First, I regress R&D expenditure on a linear time trend:

$$\text{R\&D expenditure}_{i,t} = A_{0i} + A_{1i}\, t + e_i, \qquad (1)$$

where t ranges from one to ten (corresponding to years 1997 to 2006) and i = firm.

Estimating this equation gives us the trend value of R&D expenditure. Residuals around this trend line are calculated as the actual R&D expenditure minus the trend value of R&D expenditure. The standard deviation of these residuals provides an absolute measure of R&D expenditure volatility for each firm. However, this measure is increasing in the size of R&D expenditures, so larger R&D spenders would tend to have larger standard deviations.

Therefore, in the second step, I divide the standard deviation of the residuals about the R&D time-trend by the mean R&D expenditure over the ten year study period:

$$\text{R\&D expenditure volatility} = s_i \div \bar{x}_i \qquad (2)$$

where s = the standard deviation of R&D expenditure residuals about the time-trend, i = firm, and $\bar{x}$ = the mean R&D expenditure over time.

This calculation provides us with a relative measure of R&D expenditure volatility that incorporates the firm's level of R&D spending.

3.3.2 Analyst Earnings Forecast Error

Prior research finds that analyst earnings forecast accuracy is an effective measure of corporate opacity (Barron *et al.*, 1998). Following Anderson *et al.* (2009), analyst earnings forecast accuracy is calculated as the difference between the mean analyst earnings forecast and the actual earnings for that quarter, divided by the average of the mean analyst earnings forecast and the actual earnings for that quarter. For each year, I take the mean value of analyst earnings forecast error across the four quarters.

3.3.3 Bid-Ask Spread

As discussed above, the firm's bid-ask spread is another measure of corporate opacity. I compute the bid-ask spread as the ask price minus the bid price divided by the average of the bid and the ask prices. To compute a measure of the bid-ask spread, I average all trades for each firm at month-end closing prices, and then calculate a yearly average based on these 12 observations.

3.3.4 R&D Intensity

R&D intensity is measured as annual R&D expenditure divided by firm sales.

3.3.5 Firm Age

The passage of time does not have a linear, or constant, influence on firm performance over time. The passage of one more year for a 25 year old firm is not as significant as the passage of one more year for a three year old firm. An arbitrary cutoff point of ten years of age was selected to distinguish younger firms from older firms. (The results presented in this paper are robust to selecting other ages as cutoff points between younger and older firms.) Firms whose initial public offering occurred in the most recent ten years of the study (from 1997 to 2006) are considered young firms. If the firm's initial public offering occurred after 1996, a binary variable denoting firm age is set to one. Otherwise, the binary variable is set to zero.

3.4 Control variables

There is a broad literature providing empirical support for many different sources of influence on Tobin's q. I isolate those influences before testing my research hypothesis. The following set of variables control for firm-specific and industry effects. Highly concentrated industries are viewed as less competitive; firms in such industries enjoy high entry barriers and may appropriate economic rents (McGahan and Porter, 1997). Therefore, I include the U.S. Economic Census' measure of industry concentration (market share of the twenty largest firms in each four digit NAICS industry). Tobin's q is generally viewed to be an indication of the firm's future growth prospects (Hayashi and Inoue, 1991). Firm sales growth over the previous year is included to control for this influence. Earnings per share (net income divided by shares outstanding) is included to capture the effect of firm profitability on Tobin's q (Erickson and Whited, 2000), and the level of firm sales is included to control for firm size (Montgomery and Wernerfelt, 1988). In addition to being one of the study variables, R&D intensity is also included as a control variable, since several researchers have shown a direct relationship between R&D intensity and firm performance (Jaffe, 1986; Lev and Sougiannis, 1996; Hall *et al.*, 2005). Firm value has been shown to decrease over corporate diversification (Berger and Ofek, 1995; Campa and Kedia, 2002). An entropy index (Theil, 1967) is used to measure firm diversification [36], which is calculated as follows:

$$\text{Firm diversification} = \sum_{n=1}^{\#ofdivisions} [P_n * \ln(1 \div P_n)] \qquad (3)$$

where P_n = percentage of firm revenues derived by division n. Multiple divisions that are reported in the same six digit NAICS code are treated as one division.

Lang, Ofek and Stulz (1996) find that firm leverage effects Tobin's q. The firm's debt ratio (long-term debt divided by total assets) is included to control for the influence of leverage.

In practice, many firms set R&D spending targets as a percentage of expected firm sales (Scherer, 2001; Neelankavil and Alaganar, 2003; Tubbs, 2007). In all specifications, I include a measure of sales volatility, which is calculated using the same methodology as R&D expenditure volatility, in order to control for the volatility in firm sales over time (Mudambi and Swift, 2011; Swift, 2013).

Finally, prior literature shows that the relationship between R&D expenditure volatility and firm performance is negative among very small firms (Mudambi and Swift, 2011; Swift, 2013). Thus, I seek to capture the unique effects that are attributable to very small firms. I include a dummy variable that is set to one if annual firm sales are less than $10 million, or to zero if firm sales is greater than or equal to $10 million.

4 Empirical analysis

4.1 Descriptive Statistics

Table 1 presents the summary statistics of the sample data.

In order to correct for the skewed distribution of the measure of firm value, bid-ask spread, analysts' earnings forecast error, firm size, firm leverage, and R&D intensity, these variables are log-transformed. Note that analyst earnings forecast accuracy and bid-ask spread are negatively correlated with firm value, which is consistent with a broad body of literature asserting that information asymmetry is positively related to the firm's cost of capital (Easley and O'Hara, 2004). However, note that while prior literature suggests that firm level R&D intensity is a determinant of corporate opacity (Aboody and Lev, 2000) the correlation between R&D intensity and analyst earnings forecast accuracy or bid ask spread is quite weak, and the correlation between R&D intensity and firm value is positive. This finding is consistent with a much broader literature arguing that high performing firms maintain a higher level of R&D intensity and continue to re-invest in their innovative capabilities (Jaffe, 1986; Lev and Sougiannis, 1996; Hall *et al.*, 2005).

Note that R&D expenditure volatility is only weakly correlated with R&D intensity, suggesting that R&D volatility captures a different dimension of firm behavior than R&D intensity. While a common view posits that R&D expenditure is set as a fixed percentage of firm Fosales (Scherer, 2001; Tubbs, 2007), it is interesting to note that R&D expenditure volatility is positively correlated to sales volatility, but only at r = 0.40.

4.2 Primary Tests

Multiple regression analysis is used to test the research hypothesis. In all equations, the t-values are corrected for heteroskedasticity using estimated generalized least squares (EGLS). Dummy variables are used to estimate the fixed effect of each year. In the specifications tested below, I regress Tobin's q for each firm-year on the average level of R&D expenditure volatility observed over the study period for each firm (Mudambi and Swift, 2011; Swift, 2013). I take this approach because prior research shows that Tobin's q is quite sticky. That is, q moves sluggishly over time, and is heavily influenced by the firm's prior performance (Lang *et al.*, 1989). In this analysis, I evaluate whether R&D expenditure volatility is related to *sustained* firm performance over the study period.

Table 2 shows the results of the regression analyses used to evaluate Hypotheses 1 and 2.

Hypothesis 1 states that the relationship between R&D expenditure volatility and firm value is stronger among firms with higher levels of R&D intensity. Column one shows the regression equation estimates using control variables only. Column two shows the regression estimates including the measure of R&D expenditure volatility. Note that the explanatory power of the specification using

Table 1 Summary Statistics.

Variable*	n	Mean	Std. Dev.	1	2	3	4	5	6	7	8	9	10	11
1. Tobin's q	17,022	0.28	1.17											
2. R&D Expenditure Volatility	16,693	0.34	0.28	0.15										
3. Analyst Forecast Error	8,879	0.75	3.19	-0.09	0.03									
4. Bid-Ask Spread	8,705	0.01	0.03	-0.12	0.01	0.06								
5. R&D Intensity	17,022	0.31	0.73	0.26	0.07	-0.02	0.00							
6. Sales Volatility	16,866	0,31	0.30	0.31	0.40	0.02	0.01	0.53						
7. Firm Growth	17,022	0.51	5.86	0.06	0.03	0.00	0.02	0.04	0.14					
8. Firm Profitability	17,022	-42.72	5,36	0.01	0.01	-0.13	-0.08	0.00	0.00	0.00				
9. Firm Size	17,022	4.63	2.49	-0.24	-0.27	-0.07	-0.16	-0.46	-0.46	-0.07	-0.01			
10. Industry Concentration	17,022	56.74	15.62	0.13	0.05	0.01	-0.04	0.19	0.17	0.03	0.00	-0.03		
11. Corporate Diversification	17,022	0.20	0.36	-0.16	-0.09	-0.04	-0.05	-0.18	-0.19	-0.03	0.00	0.44	-0.11	
12. Firm Debt	17,022	0.13	0.19	0.07	0.07	-0.01	-0.01	-0.02	0.04	-0.01	0.00	0.08	-0.03	0.08

* Notes: Tobins q = ln(q); R&D Volatility = standard deviation of R&D residuals about time trend / mean R&D expenditure;
Analyst earnings Forecast Error = ln(((mean estimate - actual earnings) / (mean estimate + actual) / 2) + 1)
Bid-ask spread =ln(abs(ask price - bid price) / ((bid price + ask price) / 2) + 1)
Corporate Diversification = entropy index by six digit NAICS industry; R&D intensity = ln(R&D/sales+1);
Sales Volatility = standard deviation of sales residuals about time trend / mean sales; Firm Profitability = EPS;
Firm Size = ln(total sales + 1); Firm debt = ln(debt ratio + 1); Industry Concentration = marketshare of top 20 firms.

only control variables shown in column one is statistically significant, based on its F-ratio. An incremental F-test shows that the explanatory power of the specification shown in column two is statistically significantly greater than the controls-only model shown in column one. The parameter estimate on R&D expenditure volatility is positive and statistically significant. This observation is consistent with prior research showing that R&D expenditure volatility is positively related to firm performance (Mudambi and Swift, 2011; Mudambi and Swift, 2013; Swift, 2013).

Column three includes the interaction of R&D expenditure volatility and R&D intensity. Note that the parameter estimates on R&D expenditure volatility, R&D intensity and the interaction of R&D volatility and R&D intensity are all positive and statistically significant. In addition, the incremental F-test indicates that the explanatory power of this specification is statistically significantly greater than the R&D volatility only specification shown in column two. While R&D intensity can increase corporate opacity, the positive parameter estimate is consistent with research indicating that R&D intensity increases firm value (Jaffe, 1986; Hall *et al.*, 2005). Using R&D intensity as a measure of the intangible value of the firm, Hypothesis 1 is supported.

Hypothesis 2 states that the relationship between R&D expenditure volatility and firm value is stronger among younger firms. The results of this test are shown in Table 2. Column four includes the measures of R&D expenditure volatility, a young firm indicator, and the interaction of the young firm indicator and R&D expenditure volatility. An incremental F-test indicates that the explanatory power of this specification is statistically significantly greater than the R&D volatility only specification shown in column two. The parameter estimate on R&D expenditure is once again positive and statistically significant. The parameter estimate on the young firm variable is positive and statistically significant. Although younger firms are generally more opaque, *ceteris paribus* they are also more valuable than older firms (Anderson *et al.*, 2009). Thus the positive coefficient estimate on firm age is consistent with previous literature.

The interaction of R&D volatility and the young firm indicator is positive and statistically significant. Among younger firms, the relationship between R&D expenditure volatility and firm value is more positive. Using firm age as a measure of the intangible nature of the firm, Hypothesis 2 is supported.

Table 3 shows the results of the regression analyses used to evaluate Hypotheses 3A and 3B. I use a smaller dataset to evaluate these hypotheses, since not all firms are followed by investment analysts. In tests results presented Table 3 include only those firms that have an analyst following, and report bid-ask spreads in CRSP.

Hypothesis 3A states that the relationship between R&D expenditure volatility and firm value increases as analysts' earnings forecast errors increase. Column one presents the controls only specification using this smaller dataset. Column two presents the specification including the measure of R&D expenditure volatility. Once again, note that there is a statistically significant, positive relationship between R&D expenditure volatility and firm value, which is consistent with prior research (Mudambi and Swift, 2011; Mudambi and Swift, 2013; Swift, 2013). Column three includes the measures of R&D expenditure volatility, analysts' earnings forecast error and the interaction of analysts' earnings forecast error and R&D expenditure volatility. An incremental F-test indicates that the explanatory power of this specification is statistically significantly greater than the R&D volatility only specification shown in column two. The parameter estimate on R&D expenditure is once again positive and statistically significant. The parameter estimate on analysts' earnings forecast error is negative and statistically significant, which is consistent with prior literature establishing a negative relationship between analyst forecast accuracy and firm value (Clarkson *et al.*, 1996; Easley and O'Hara, 2004). The interaction of R&D volatility and analysts' earnings forecast error is positive and statistically significant. As analysts' earnings forecast error increases, the relationship between R&D expenditure volatility and firm value increases. Hypothesis 3A is supported.

Hypothesis 3B states that the relationship between R&D expenditure volatility and firm value increases as bid-ask spreads increase. Column four of Table 3 includes the measures of R&D expenditure volatility, bid-ask spread and the interaction of bid-ask spread and R&D expenditure volatility. An incremental F-test indicates that the explanatory power of this specification is statistically significantly greater than the R&D volatility only specification shown in column two. The parameter estimate on R&D expenditure is positive and statistically significant. The parameter estimate on bid-ask spread is negative and statistically significant, which is consistent with prior literature establishing a negative relationship between bid-ask spread and firm value (Copeland and Galai, 1983; Glosten and Milgrom, 1095; Venkatesh and Chiang, 1986; Diamond and Verrecchia, 1991). The interaction of R&D volatility and bid-ask spread is positive and statistically significant. As the bid-ask spread increases, the relationship between R&D expenditure volatil-

Table 2 R&D Volatility and Intangible Assets.

These estimates show the impact that information asymmetry has on the relationship between R&D volatility and firm performance. *t-statistics in italics below parameter estimates.*

	(1) Base Model		(2) including R&D Expenditure Volatility		(3) including R&D Intensity		(4) including Firm Age	
Intercept	-043	***	-046	***	-0.36	***	-0.46	***
	-11.75		*-12.35*		*-9.12*		*-12.18*	
R&D Expenditure Volatility			0.16	***	0.11	***	0.10	***
			4.47		*2.90*		*2.65*	
R&D Volatility * R&D Intensity					0.14	***		
					3.12			
R&D Volatility * Firm Age							0.28	***
							3.82	
Firm R&D Intensity	0.11	***	0.12	***	0.07	***	0.10	***
	7.26		*7.97*		*3.12*		*6.88*	
Firm Age							0.07	**
							2.43	
Corporate Diversification	-0.25	***	-0.26	***	-0.24	***	-0.25	***
	-12.01		*-12.26*		*-11.78*		*-12.22*	
Sales Volatility	0.70	***	0.62	***	0.61	***	0.66	***
	18.05		*15.07*		*14.99*		*16.18*	
Firm Profitability	0.00	***	0.00	***	0.00	***	0.00	***
	3.31		*3.26*		*3.14*		*3.20*	
Firm Size	0.02	***	0.03	***	0.02	***	0.02	***
	5.09		*5.90*		*4.68*		*5.45*	
Firm Debt-Ratio	0.49	***	0.50	***	0.54	***	0.53	***
	12.93		*13.35*		*14.91*		*14.76*	
Firm Growth	0.00	***	0.00	***	0.00	***	0.00	***
	2.42		*2.69*		*2.76*		*2.74*	
Dummy (if Sales < 10)	0.62	***	0.62	***	0.62	***	0.59	***
	20.31		*20.14*		*20.05*		*19.27*	
Industry Concentration	0.00	***	0.00	***	0.00	***	0.00	***
	7.37		*7.08*		*7.70*		*7.24*	
R-Square	0.163		0.165		0.170		0.172	
F-Statistic	197.80		186.77	***	174.34	***	176.17	***
Incremental F test			2.39	**	5.62	***	6.77	***
	n=17218		n=17016		n=17016		n=17016	

*** p < .01, ** p < .05, * p < .10; Note: Equations are estimated with dummy variables for each year.

ity and firm value increases. Hypothesis 3B is supported.

Using four very different measures of information asymmetry (or corporate opacity), I find sufficient evidence supporting my main research hypothesis.

4.3 Sub-Sample Analysis: Using Chemicals Firms Only

Of particular interest to our readers is the chemicals industry, which is a subset of the sample of all manufacturing firms used to test the hypotheses above. Table 4 below presents the results of our regression analysis using only the observations from chemicals firms (NAICS 325).

Column one of Table 4 shows the results using R&D intensity as the measure of firm-level intangible capabilities, and column two of Table 4 shows the results using firm age as the measure. Column three of Table 4 shows the results of the specification using analyst earnings forecast accuracy as the measure of information asymmetry. Column four shows the results using bid-ask spread as the measure of information asymmetry. Note that the cross terms of R&D expenditure volatility and the measures of intangible capabilities or information asymmetry are positive and statistically significant in three of the four specifications. Using a sub-sample of firms from the chemicals industry, the specification using analyst earnings forecast accuracy is no longer statistically significant. However, the main results are supported in the chemicals industry by using bid-ask spread, R&D intensity and firm age as measures of information asymmetry and firm-level intangible capabilities.

These results strongly suggest that the main findings observed across all manufacturing industries also hold in the chemicals industry in particular. The importance of R&D expenditure volatility to investors increases as information asymmetry between the firm and its investors increases.

5 Discussion

If a highly volatile R&D expenditure profile is a reasonable indicator of proactive R&D management, the findings in this paper have important ramifications. Outside investors may interpret volatile R&D expenditures as evidence of effective governance of the R&D function. Since prior research shows that investors place greater emphasis on secondary sources information when relatively little investor information is available (Sanders and Boivie, 2004: 168), such cues may be particularly valuable to investors that are evaluating opaque firms.

Changes to R&D expenditure are commonly viewed as evidence of myopic decision-making by management. R&D spending is more likely to be reduced when the CEO approaches retirement (Dechow and Sloan, 1991) or when the firm is likely to miss an earnings objective (Baber *et al.*, 1991). Firm managers may consider steady R&D expenditure overtime as a demonstration of their commitment to the innovation process. Evidence presented in this paper suggests that would be a mistake.

I began this paper by pointing to new research that has identified a positive link between R&D expenditure volatility and firm performance, noting that this finding is in contrast to prior research suggesting that stable R&D investments may be more beneficial to firm innovation (Mudambi and Swift, 2011; Mudambi and Swift, 2013; Swift, 2013). I discussed the detrimental effects of corporate opacity, and the research suggesting that under conditions of information asymmetry, investors place greater reliance on secondary sources of information such as corporate governance processes in order to evaluate the firm's prospects. I suggest that R&D expenditure volatility is a form of information disclosure, and that investors place greater emphasis on this type of secondary information under conditions of higher information asymmetry. I identify four determinants of corporate opacity that are particularly relevant to firm investors: the firm's level of R&D intensity; the age of the firm; the accuracy of investment analyst earnings forecasts; and the bid-ask spread.

The first finding of this paper is the relationship between R&D expenditure volatility and firm value is higher among firms with higher levels of R&D intensity. Two likely reasons for this relationship exist. First, since R&D projects are so difficult to evaluate by outsiders (Bernardo *et al.*, 2001; Stein, 2003), and the accounting and market information on R&D is so incomplete (Aboody and Lev, 2000), investors place greater evidence on secondary indicators of R&D prospects, such as R&D expenditure volatility. Second, since the importance of R&D to the firm's value increases with its R&D intensity (Tasker, 1998a; 1998b), it follows that investors would place greater evidence on any disclosure that is useful in evaluating the firm's R&D prospects. R&D expenditure volatility takes on greater importance to investors as a form of information disclosure among more R&D intensive firms.

The second finding of this paper is that the relationship between R&D expenditure volatility and firm value is stronger in firms that are less than ten years from their initial public offering (IPO). Since relatively younger firms have been observed for relatively less time than older firms, investors

Table 3 R&D Volatility and Information Asymmetry.

These estimates show the impact that information asymmetry has on the relationship between R&D volatility and firm performance. *t-statistics in italics below parameter estimates.*

	(1) Base Model		(2) including R&D Expenditure Volatility		(3) including Analyst Earnings Forecast Accuracy		(4) including Bid-Ask Spread	
Intercept	0.11	**	0.03		0.25	***	-1..12	***
	1.97		*0.44*		*4.32*		*-14.89*	
R&D Expenditure Volatility			0.26	***	0.15	**	0.43	***
			4.58		*2.14*		*2.44*	
R&D Volatility * Analyst Earnings Forecast Eror					0.43	**		
					3.23			
R&D Volatility * Bid-Ask Spread							0.06	**
							1.99	
Analyst Earnings Forecast Error					-0.51	***		
					-13.15			
Bid-Ask Spread							-0.44	***
							-30.20	
Firm R&D Intensity	0.12	***	0.13	***	0.06	**	-0.05	**
	4.07		*4.42*		2.28		*-1.97*	
Corporate Diversification	-0.28	***	-0.31	***	-0.32	***	-0.22	***
	-10.40		*-11.05*		*-11.52*		*-8.21*	
Sales Volatility	0.26	***	0.14	***	0.14	**	-0.07	***
	4.16		*2.18*		*2.03*		*-1.15*	
Firm Profitability	0.05	***	0.04	***	0.02	***	0.02	***
	8.73		*7.44*		*3.12*		*4.16*	
Firm Size	0.00	***	0.01	***	0.00	***	-0.12	***
	0.67		*1.32*		*-0.17*		*-15.19*	
Firm Debt-Ratio	-0.06	***	-0.04		-0.02		0.15	***
	-0.77		*-0.56*		*-0.33*		*2.18*	
Firm Growth	0.03	***	0.03	***	0.03	***	0.02	***
	5.27		*5.49*		*5.31*		*4.55*	
Dummy (if Sales < 10)	0.27	***	0.30	***	0.28	***	0.44	***
	4.15		*4.55*		*4.31*		*7.18*	
Industry Concentration	0.00	***	0.00	***	0.00	***	0.00	***
	2.80		*3.51*		*4.86*		*5.87*	
R-Square	0.090		0.095		0.130		0.238	
F-Statistic	35.17		34.91	***	45.52	***	94.65	***
Incremental F test			1.66	**	11.78	***	11.78	***
	n=6542		n=6373		n=6373		n=6373	

*** $p < .01$, ** $p < .05$, * $p < .10$

have more difficulty in evaluating the true prospects of their R&D efforts. Under these conditions, investors place greater emphasis on secondary sources of information. Note that R&D expenditure volatility has a stronger, positive influence on firm value among younger firms.

The third finding of this paper is that information asymmetry between the firm and its investors increases, the relationship between R&D expenditure volatility and firm value increases. Using the most comprehensive measure of corporate opacity, analyst earnings forecast error, I find that the relationship between R&D expenditure volatility and firm value is stronger among more opaque firms. This finding provides further evidence that R&D expenditure volatility is a real form of information disclosure to outside investors, and that investors regard this observation as a positive indication that the firm is proactively managing its R&D function.

The final finding supports the third. Using an alternative measure of information asymmetry, the bid-ask spread on share prices on publicly traded exchanges, I find results that are consistent with results using analyst earnings forecast error. Hypothesis 3 is robust to multiple measures of information asymmetry.

These results are economically as well as statistically significant. For example, at the mean value for all variables in the sample, a 10% increase in R&D expenditure volatility results in a 1.6% increase in firm value as measured by Tobin's q. This relationship between R&D expenditure volatility and firm performance is sensitive to the level of information asymmetry between the firm and its investors. For example, if analyst earnings forecast error increases by 10% above the mean value, then a 10% increase in R&D expenditure volatility results in a 1.8% increase in firm value. Clearly, understanding the value assigned by investors to proactive R&D management under conditions of information asymmetry is significant.

Many of the findings in this paper are consistent with previous research. The evidence presented here showing that R&D intensity (Jaffe, 1986; Lev and Sougiannis, 1996; Hall *et al.*, 2005), firm youth (Anderson *et al.*, 2009) and R&D expenditure volatility (Mudambi and Swift, 2011; Mudambi and Swift, 2013; Swift, 2013) are positively related to firm value reinforces earlier findings. The negative parameter estimate on analyst earnings forecast accuracy supports earlier findings that corporate opacity results in higher cost of capital (Clarkson *et al.*, 1996; Easley and O'Hara, 2004). In the same way, the negative parameter estimate on bid-ask spread is also in line with prior research (Copeland and Galai, 1983; Glosten and Milgrom, 1985; Venkatesh and Chiang, 1986; Diamond and Verrecchia, 1991).

What are noteworthy in my empirical results are the interaction terms; the parameter estimates on the product of R&D expenditure volatility and corporate opacity are always positive. Using four different measures of corporate opacity, I present extensive evidence that R&D expenditure volatility is a form of information disclosure, and that this disclosure is more valuable when investors are struggling to understand the true prospects of future firm value.

These findings can change the way we manage R&D intensive firms, or evaluate them as investors. This study introduces a new concept to investors, researchers, R&D managers and investor relations experts. The current emphasis on the level of R&D spending is incomplete.

While much research in R&D suggest that smooth R&D spending over time indicates a firm's commitment to innovation (Grabowski, 1968; Hambrick *et al.*, 1983; Dierckx and Cool, 1989), others provide evidence that firms can overinvest in R&D. Barnett and Freeman (2001) find that firms issue too many new products, which significantly increases the likelihood of organizational failure. McMath and Forbes (1998) show that most new products fail. Demirel and Mazzucato (2012) show that R&D can dampen firm growth among large pharmaceutical firms. I suggest that R&D expenditure volatility is a valuable clue to investors that the firm is proactively managing its R&D function, preventing R&D overinvestment during periods of R&D based exploitation, and aggressively ramping up exploratory R&D spending once the value of the firm's extant competitive advantage has eroded.

R&D managers must monitor the firm's future R&D prospects aggressively. As the value of firm's current core competencies begin to wane, management has the opportunity to dramatically shift R&D resources from exploitation (innovation related to the firm's current knowledge base) to exploration (searching for new knowledge relatively distant from the firm's existing knowledge base). Such movements from exploration and exploitation based R&D activities may result in a volatile R&D expenditure over time (Mudambi and Swift, 2011; Mudambi and Swift, 2013). In this paper, I assert that rather than seeking smooth, consistent R&D spending over time, firms may wish to promote R&D spending changes, and to ensure that the firm's stakeholders understand the reasons for these fluctuations. By increasing efforts to explain why the firm has significantly changes its level of R&D expenditure, managers may mitigate the market's propensity to underestimate the true value of the firm in the presence of information asym-

Table 4 Chemicals Industry Results

These following estimates show the impact that information asymmetry has on the relationship between R&D volatility and firm performance in the chemicals industry. *t-statistics in italics below parameter estimates.*

	(1) including R&D Intensity		(2) including Firm Age		(3) including Analyst Earnings Forecast Accuracy		(4) including Bid-Ask Spread	
Intercept	0.25	***	0.16	**	0.80	***	-0.12	
	3.48		*2.46*		*7.91*		*-0.90*	
R&D Expenditure Volatility	0.12	*	0.14	**	0.12		0.52	**
	1.85		*2.29*		*1.12*		*2.12*	
R&D Volatility * R&D Intensity	0.16	***						
	2.90							
R&D Volatility * Firm Age			0.37	***				
			2.61					
R&D Volatility * Analyst Earnings Forecast Error					0.16			
					0.57			
R&D Volatility * Bid-Ask Spread							0.07	*
							1.79	
Firm R&D Intensity	-0.01		0.05	***	-0.01		-0.08	**
	-0.43		*2.78*		*-0.31*		*-2.50*	
Firm Age			-0.05	***				
			-0.84					
Analyst Earnings Forecast Error					-0.30	***		
					-2.73			
Bid-Ask Spread							-0.28	***
							-10.51	
Corporate Diversification	-0.41	***	-0.41	***	-0.46	***	-0.35	***
	-8.29		*-8.56*		*-7.54*		*-5.80*	
Sales Volatility	0.34	***	0.38	***	0.16	**	0.07	
	5.92		*6.53*		*2.02*		*0.96*	
Firm Profitability	0.000003	***	0.000003	***	0.01		-0.003	
	14.55		*14.48*		*0.55*		*-0.21*	
Firm Size	0.04	***	0.04	***	0.01		-0.05	***
	4.12		*5.11*		*0.77*		*-3.14*	
Firm Debt-Ratio	0.42	***	0.43	***	-0.16		-0.31	**
	5.84		*5.86*		*-1.37*		*-2.55*	
Firm Growth	0.00	**	0.00	**	0.01	**	0.01	**
	2.14		*2.19*		*2.57*		*2.14*	
Dummy (if Sales < 10)	0.46	***	0.45	***	0.05		0.20	***
	8.81		*8.75*		*0.62*		*2.63*	
R-Square	0.170		0.184		0.126		0.205	
F-Statistic	174.34	***	47.05	***	10.72		18.28	***
	n = 3,993		n = 3,993		n = 1,442		n = 1,442	

*** p < .01, ** p < .05, * p < .10; Note: Equations are estimated with dummy variables for each year.

metry (Izquierdo and Izquierdo, 2007).

Investors in R&D intensive firms can use R&D expenditure volatility as an important cue that prompts focused investigation. In certain situations, fluctuations in R&D spending indicate that the firm is manipulating earnings (Dechow and Sloan, 1991; Baber *et al.*, 1991). Yet in general, this observed volatility can be evidence that the firm transitions to exploratory R&D activities during periods of extreme industry change that calls for new forms of innovation (Mudambi and Swift, 2011; Mudambi and Swift, 2013). Investors that observe high levels of R&D expenditure volatility may wish to undertake focused investigation into the firm's activities that may shed light on the sources, and ramifications, of this observed R&D volatility.

Despite the compelling evidence presented here, much work can be done to address gaps in this research. This nascent line of inquiry presents new and important questions. Future research in finance and accounting can determine how to differentiate between firms using R&D spending as a simply a buffer with which to manage short-term earnings and firms that are moving between modes of R&D-based exploration and exploitation. More work can be done exploring the role that boundary spanners play in brokering the difficult discussions that must occur between the professional guilds of management and science as R&D budgets are adjusted (Mudambi and Swift, 2009). Management scholars can employ case study methods that identify the tactics that high performing companies use to determine when and how R&D expenditure spending should be changed as market conditions warrant. Prior research has found that R&D expenditure volatility can be detrimental in small firms, firms competing in slow clockspeed industries, or highly diversified firms (Mudambi and Swift, 2011), yet very valuable among firms with higher levels of organizational slack (Swift, 2013). Research in multiple disciplines can identify other variables that enhance or mitigate the relationship between R&D volatility and firm value.

References

Aboody, D., Lev, B. (2000): Information asymmetry, R&D, and insider gains, *Journal of Finance*, **LV** (6), pp. 2747-2766.

Anderson, R., Duru, A., Reeb D. (2009:) Founders, heirs, and corporate opacity in the United States, *Journal of Financial Economics*, **92**, pp. 205-222.

Arrow, K. (1962): Economic welfare and the allocation of resources for invention, in: *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Princeton, NBER and Princeton University Press, pp. 609-625.

Baber, W.R., Fairfield, P.M., Haggard, J.A. (1991): The effect of concern on discretionary spending decisions: the case of research and development, *The Accounting Review,* **66** (5), pp. 818-829.

Bailey, J., Ford, C. (1996): Management as science versus management as practice in postgraduate business education, *Business Strategy Review*, **7** (4), pp. 7-12.

Barnett, W.P., Freeman, J. (2001): Too much of a good thing? Product proliferation and organizational failure, *Organization Science*, **12** (5), pp. 539-558.

Barron, O.E., Kim, O., Lim, S.C., Stevens, D.E. (1998): Using analysts' earnings forecast to measure properties of analysts' information environment, *The Accounting Review*, **73** (4), pp. 421-433.

Berger, P.G., Ofek, E. (1995): Diversification's effect on firm value, *Journal of Financial Economics*, **37**, pp. 39-65.

Berger, P.G., Udell, G.F. (1995): Relationship lending and lines of credit in small firm finance, *Journal of Business*, **68** (3), pp. 351-381.

Bernardo, A.E., Cai, H., Luo, J. (2001): Capital budgeting and compensation with asymmetric information and moral hazard, *Journal of Financial Economics*, **61**, pp. 311-344.

Boot, A.W.A., Thakor, A.V. (1994): Moral hazard and secured lending in an infinitely repeated credit market game, *International Economic Review*, **35**, pp. 899-920.

Campa, J.M., Kedia, S. (2002): Explaining the diversification discount, *Journal of Finance*, **LVII**(4), pp. 1731-1762.

Chen, W.R., Miller, K.D. (2007): Situational and institutional determinants of firm's R&D search intensity, *Strategic Management Journal*, **28**, pp. 369-281.

Chung, K.H., Pruitt, S.W. (1994): A simple approximation of Tobin's q, *Financial Management*, **23** (3), pp. 70-74.

Ciampi, F., Gordini, N. (2009): Default prediction modeling for small enterprises: Evidence from small manufacturing firms in northern and central Italy, *Oxford Journal*, **8** (1), pp. 13-29.

Clark K.B., Fujimoto T. (1991): *Product development performance: strategy, organization and management in the world auto industry*, Harvard Business Press.

Clark K.B., Chew W.B., Fujimoto T. (1987): Product development in the world auto industry, *Brookings Papers on Economic Activity*, **3**, pp. 729-771.

Clarkson, P., Guedes, J., Thompson, R. (1996): On the diversification, observability, and measurement of estimation risk, *Journal of Financial and Quantitative Analysis*, **31**, pp. 69-84.

Copeland, T.E., Galai, D. (1983): Information effects on the bid-ask spread, *Journal of Finance*, **38**, pp. 1457-69.
CRSP Stocks. (March, 2011): *1997 to 2006*, Available: Center For Research in Security Prices. Graduate School of Business. University of Chicago Retrieved from Wharton Research Data Service.
Dechow, P.M., Sloan, R.G. (1991): Executive incentives and the horizon problem: An empirical investigation, *Journal of Accounting and Economics*, **14**, pp. 51-89.
Demirel, P., Mazzucato, M. (2012) Innovation and firm growth: Is R&D worth it? *Industry and Innovation*, **19** (1), pp. 45-62.
Devinney, T. (1993): How well do patents measure new product activity? *Economic Letters*, **41** (4), pp. 447-450.
Diamond, D.W., Verrecchia, R.E. (1991): Disclosure, liquidity and the cost of capital, *Journal of Finance*, **XLVI**(4), pp. 1325-1359.
Dierickx, I., Cool, K. (1989): Asset stock accumulation and sustainability of competitive advantage, *Management Science*, **35** (12), pp. 1504-1511.
DiMasi J.A., Hansen W., Grabowski H.G. (2003): The price of innovation: new estimates of drug development costs, *Journal of Health Economics*, **22** (2), pp. 151-185.
Dyer, J.H. (1996): Specialized supplier networks as a source of competitive advantage: Evidence from the auto industry, *Strategic Management Journal*, **17** (4), pp. 271-292.
Easley D., O'Hara. M. (2004): Information and the cost of capital, *Journal of Finance*, **59**, pp. 1553-1583.
Erickson, T., Whited, T.M. (2000): Measurement error and the relationship between investment and q, *Journal of Political Economy*, **108** (5), pp. 1027-1057.
Gagnon M., Lexchin, J. (2008): The cost of pushing pills: A new estimate of pharmaceutical promotion expenditures in the United States, *PLoS-Medicine*, **5** (1), pp. 29-33
Glosten, L.R., Milgrom, P.R. (1985): Bid-Ask and transaction prices in a specialist market with heterogeneously informed traders, *Journal of Financial Economics*, **14**, pp. 71-100.
Grabowski, H.G. (1968): The determinants of industrial research and development: a study of the chemical drug and petroleum industries, *Journal of Political Economy*, **76**, pp. 292-306.
Gu F., Li, J.Q. (2007): The credibility of voluntary disclosure and insider stock transactions, *Journal of Accounting Research*, **45** (4), pp. 771-810.
Hall, B.H., Jaffe, A., Trajtenberg, M. (2005): Market value and patent citations, *RAND Journal of Economics*, **36** (1), pp. 16-38.
Hambrick, D.C., MacMillan, I.C., Barbosa, R.R. (1983): Business unit strategy and changes in the product R&D budget, *Management Science*, **29** (7), pp. 757-769.
Hannan, M.T., Freeman, J. (1984): Structural inertia and organizational change, *American Sociological Review*, **49**, pp. 149-164.
Harryson S.J., Dudkowski R., Stern A. (2008): Transformation networks in innovation alliances – the development of Volvo C70, *Journal of Management Studies*, **45** (4), pp. 745-773.
Hayashi F., Inoue, T. (1991): The relations between firm growth and q with multiple capital goods: theory and evidence from panel data on Japanese firms, *Econometrica*, **59** (3), pp. 731-754.
Healy, P., Palepu, K. (2001): Information asymmetry, corporate disclosure and the capital markets: a review of the empirical disclosure literature, *Journal and Accounting and Economics*, **31**, pp. 405-440.
Izquierdo, S., Izquierdo, L. (2007): The impact of quality uncertainty without asymmetric information on market efficiency, *Journal of Business Research*, **60** (8), pp. 858-867.
Jaffe, A. (1986): Technology opportunity and spillovers of R&D: evidence from firms' patents, profits and market value, *American Economic Review*, **76**, pp. 984-1001.
Lang, L., Ofek E., Stulz R. (1996): Leverage, investment and firm growth, *Journal of Financial Economics*, **40**, pp. 3-29.
Lang L., Stulz R., Walkling, R. (1989): Tobin's q and the gains from successful tender offers, *Journal of Financial Economics*, **24**, pp. 137-154.
Lev, B., Sougiannis, T. (1996): The capitalization, amortization and value-relevance of R&D, *Journal of Accounting and Economics*, **21**, pp. 107-138.
Levitas, E., Chi, T. (2010): A look at the value creation effects of patenting and capital investment through a real options lens: the moderating role of uncertainty, *Strategic Entrepreneurship Journal*, **4** (3), pp. 212-233.
March, J.G. (1998): *Decisions and Organizations*, Basil Blackwell, Oxford.
March, J.G. (1991): Exploration and exploitation in organizational learning, *Organization Science*, **2**, pp. 71-87.
March, J.G. (1996): Continuity and change in theories of organizational action, *Administrative Science Quarterly*, **41**, pp. 278–287.
March, J.G. (2006): Rationality, foolishness, and adaptive intelligence, *Strategic Management Journal*, **27**, pp. 201–214.
McGahan, A.M., Porter, M.E. (1997): How much does industry matter, really? *Strategic Management Journal*, Summer Special Issue, 18, pp. 15-30.
McMath, M.R., & Forbes, T. (1998): *What were they thinking?* New York: Times Business-Random

House.
Meremadi, M., Musso, C. Oxgaard, J. (2013): Chemical innovation: An investment for the ages. McKinsey & Company; available at http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&ved=0CEsQFjAE&url=http%3A%2F%2Fwww.mckinsey.com%2F~%2Fmedia%2Fmckinsey%2Fdotcom%2Fclient_service%2FChemicals%2FPDFs%2FChemical_innovation_An_investment_for_the_ages.ashx&ei=maUOUpKwDaThyQGFroEw&usg=AFQjCNG2nbtcbCtj20ODUby3PyHHAWZJoQ&sig2=dqZDoCgzxUp07x5xYF2lVA&bvm=bv.50768961, accessed August 16, 2013.
Miller, D., Chen, M.J. (1996): The simplicity of competitive repertoires: An empirical analysis, *Strategic Management Journal*, **17**, pp. 429-439
Montgomery, C., Wernerfelt, B. (1988): Diversification, Ricardian rents, and Tobin's q, *RAND Journal of Economics*, **19**, pp. 623-32.
Mudambi, R., Swift, T. (2009): Professional guilds, tension and knowledge management, Research *Policy*, **38** (5), pp. 636-645.
Mudambi, R., Swift, T. (2011): Proactive R&D management and firm growth: a punctuated equilibrium model, *Research Policy*, **40**, pp. 429-440.
Mudambi, R., Swift. T. (2013) Knowing when to leap: Transitioning between exploitative and explorative R&D, *Strategic Management Journal*, (DOI: 10.1002/smj.2097).
Nystrom, P.C., Starbuck, W.H. (1984): To avoid organizational crises, unlearn, *Organizational Dynamics*, pp. 53-65.
Oriani, R., Sobrero M. (2008): Uncertainty and the market valuation of R&D within a real options logic, *Strategic Management Journal*, **29** (4), pp. 343-361.
Perry, S., Grinaker, R. (1994:) Earnings expectations and discretionary research and development spending, *Accounting Horizons*, **8** (4), pp. 43-51.
Pfeffer, J., Fong, C. (2002): The end of business schools? Less success than meets the eye. *Academy of Management Learning & Education*, **1** (1), pp. 78-95.
Riley, J.G. (1989): Signaling. in: Eatwell J, Milgate M, Newman P, (ed.), *Allocation. Information, and Markets*, Norton: New York, pp. 287-294.
Romanelli, E., Tushman, M.L. (1994): Organizational transformation as punctuated equilibrium: an empirical test, *Academy of Management Journal*, **37** (5), pp. 1141-1166.
Sanders, W.G. Boivie, S. (2004): Sorting things out: valuation of new firms in uncertain markets, *Strategic Management Journal*, **25**, pp. 167-186.
Scherer, F.M. (2001): The link between gross profitability and pharmaceutical R&D spending, *Health Affairs*, **20** (5), pp. 216-220.
Standard and Poors (2011): *Compustat North America*: McGraw-Hill.
Stein, J.C. (2003): *Agency, information and corporate investment*, in Constantinides G.M., Harris M., Stulz R.M. (ed.) Handbook of the Economics of Finance, Elsevier Science B.V.
Swift, T. (2013): R&D expenditure volatility and firm performance: Organizational and environmental contexts, *International Journal of Innovation and Technology Management*, **10** (3).
Tasker, S. (1998a): Bridging the information gap: Quarterly conference calls as a medium for voluntary disclosure, *Review of Accounting Studies*, **3**, pp. 137-167.
Tasker, S. (1998b): Technology company conference calls: A small sample study, *Journal of Financial Statement Analysis*, **4**, pp. 6-14.
Theil, H. (1967): *Economics and information theory*, Amsterdam: North-Holland.
Thomson-Reuters (2011): *Institutional Brokers' Estimate System*: Thomson Financial.
Tubbs, M. (2007): The relationship between R&D and company performance, *Research Technology Management*, **50** (6), pp. 23-30.
U.S. Census Bureau. (2002): *1997 economic census*, In U. S. C. Bureau (Ed.).
Venkatesh, P.C., Chiang, R. (1986): Information asymmetry and the dealer's bid-ask spread: A case study of earnings and dividend announcements, *Journal of Finance*, **XLI** (5), pp. 1089-1102.
Wernerfelt, B., Montgomery, C. (1988): Tobin's q and the importance of focus in firm performance, *American Economic Review*, **78** (1), pp. 246-250.

Practitioner's Section

Improving R&D productivity requires a balanced approach

Fang X Zhou* and Thomas Bertels**

* Valeocon Management Consulting, 127 W. 26th Street Suite 500, New York, NY 10001, United States, fang.zhou@valeocon.com

** Valeocon Management Consulting, 127 W. 26th Street Suite 500, New York, NY 10001, United States, thomas.bertels@valeocon.com

In recent years pharmaceutical companies have implemented Operational Excellence (OpEx) in their R&D organizations to improve productivity but had only limited success. Practitioners and management start to question the effectiveness of process-focused improvement methodologies. In this article, we illustrate a number of challenges OpEx practitioners face and argue that our long-held assumptions and lack of understanding of pharmaceutical R&D can prevent us from seeing the real problems. We recommend a balanced approach by integrating process management with organization's project management capability in order to better engage the stakeholders and deliver both short-term results and long-term improvement.

1 Introduction

A typical novel drug takes over 10 years and over $1Billion from discovery to market (PhRMA, 2013). The current pharmaceutical business model is being questioned due to declining R&D productivity as measured by approved drugs over R&D investments (Cockburn, 2007; Scannell et al., 2012). One key metric of productivity is cycle time of the R&D process. Reducing the time to market has numerous business benefits, such as longer exclusivity and reduced costs (Mestre-Ferrandiz et al., 2012).

Operational Excellence (OpEx) methodologies have long been used for productivity improvement (Bertels, 2003). In the past few decades, a number of new approaches emerged. The Six Sigma methodology, introduced by Motorola in 1980's, emphasizes the use of statistical tools to understand and reduce variation and improve quality. The Lean methodology, popularized by the success of the Toyota Production System, is widely used to eliminate waste and reduce cycle time for manufacturing and product development processes. Many organizations have combined these new methodologies with traditional quality improvement tools in their implementation of Operational Excellence. One common form of implementation is DMAIC, which is the acronym for Define, Measure, Analyze, Improve, and Control, a five-phase process improvement approach originated from General Electric. As illustrated in Figure 1, DMAIC is one form of the Plan-Do-Check-Act (PDCA) cycle advocated by W. Edwards Deming for scientific problem-solving and continuous improvement (Deming, 1986).

Since the 1990's, Operational Excellence methodologies have also been implemented to a varying degree in pharmaceutical manufacturing to reduce cycle time, improve quality, and control costs. In the past few years, as improving R&D productivity became an imperative, Operational Excellence was introduced to many pharmaceutical R&D organizations, ranging from DMAIC training of a small group of individuals to divisional deployment of a suite of OpEx methodologies. Management and OpEx practitioners believed that the same disciplined improvement approach applies to the pharmaceutical R&D process (from discovery of a drug target to application for regulatory approval) as well as manufacturing.

While the OpEx methodologies worked well in a project within one or two functional areas, practitioners quickly realized they faced new challenges when applying them to improve the core process (Johnstone et al., 2011; Barnhart, 2013). For example, engaging a local team in a Kaizen event to improve their own process is effective. But when the outcome is less defined and the processes intertwined among many organizations and geographical locations, a myriad of issues, from defining the right metric to gaining the right sponsorship, emerge. As a result, many OpEx efforts have made limited impact in R&D. Some practitioners were quick to blame OpEx maturity and organizational culture as the causes. But they are not unique to pharmaceutical R&D and cannot explain all the challenges. To understand these challenges, we must first examine long-held beliefs and practices taken for granted in manufacturing and service environments, and ask:

- What is fundamentally different when striving for productivity improvement in R&D as compared to manufacturing or services?
- What aspects of Operational Excellence are valid and relevant for pharmaceutical R&D? What is missing in the traditional approach?

The intent of this article is not to cover the full spectrum of the challenges facing OpEx practitioners and R&D business leaders. Instead, it focuses on one key question: What is the role of process improvement in transforming pharmaceutical R&D? In this article, to help readers appreciate the specific challenges, we first present a hypothetical case that is based on our real-life observations of implementing OpEx in many pharmaceutical R&D organizations. It is used to illustrate one aspect of R&D productivity improvement: cycle time reduction. We then link the challenges to the critical differences between pharmaceutical R&D and manufacturing or services. We believe that the understanding of these differences is fundamental to developing new perspectives and applying the right methodologies in pharmaceutical R&D. Finally, by considering the organizational reality in pharmaceutical R&D and applying the above understanding, we propose a practical approach to reduce cycle time and develop organization's capability of continuous improvement.

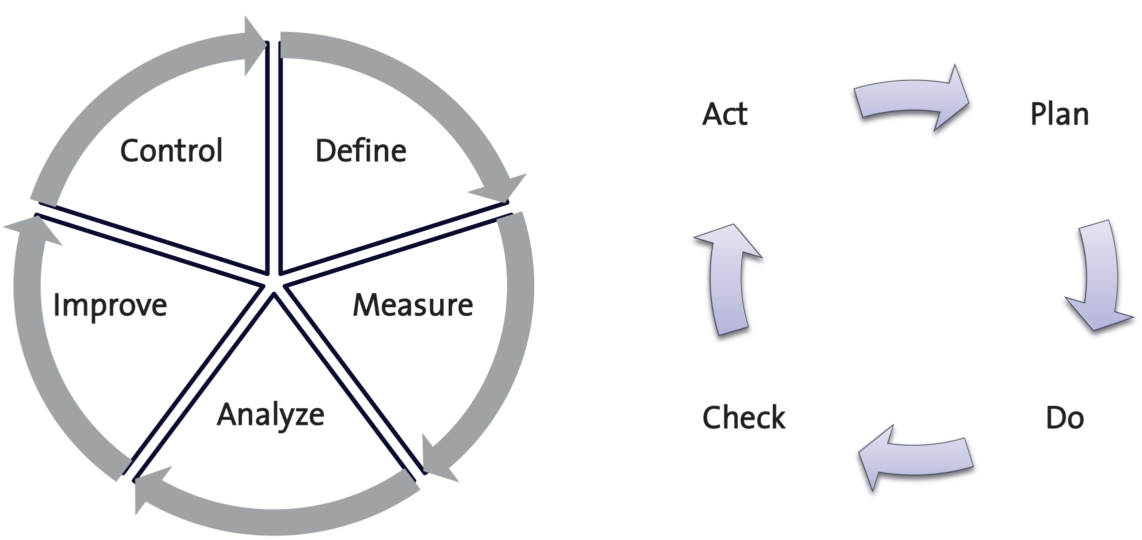
2 The Challenge: A Cycle Time Reduction Example

To illustrate the challenge in applying the traditional process improvement methodologies in pharmaceutical R&D, consider the following scenario.

In a global pharmaceutical company, a number of R&D programs were facing competition from multiple industry leaders, in some cases several months to a year behind the leading competitor. Based on external benchmarking, the executives estimated that their company's overall R&D cycle time was about the same as or slightly longer than the competitors. Therefore, it was imperative to reduce the cycle times in the process wherever possible. A cycle time reduction project was chartered to identify opportunities to streamline a sub-process that had the worst performance. The team was led by a respected functional leader and coached by an Operational Excellence veteran experienced in improving both manufacturing and transactional processes in other industries, and followed the popular DMAIC framework.

As a high-priority project, the team received strong sponsorship from top management and dedicated resources, both of which were uncommon in the early stage of OpEx deployment. As a

Figure 1 DMAIC and PDCA cycle.



result, the Define phase went smoothly, and the sponsors approved the project with a goal of reducing the average cycle time of a sub-process in Phase II clinical development by 3 months.

As soon as the team entered the Measure phase, however, they encountered major obstacles:

- The process was poorly defined and documented in various formats. The process flow varied for each program because teams developed their own way of performing common tasks. No standardization was attempted.
- Each program required some unique decision points, branches, loops, and steps in the process. No single process map could adequately describe the current state.
- With regards to cycle time, there was no operational definition or systematic measurement. The data available was incomplete and inconsistent.

The process was obviously not consistent, outliers common, and the measurement system not reliable. If the baseline was undefined, what should be the SMART (Specific, Measureable, Achievable, Relevant, and Time-bound) goal statement at the end of Measure? Should the project goal be 1) reducing the variation to have a better defined baseline or 2) reducing the average cycle time as originally chartered? Could the team achieve both objectives?

In Analyze, the cross-functional team worked to identify the root causes of the long cycle time and variation. Some common potential causes were identified based on limited information of previous programs, including

- Resource constraints (both internal and external)
- Technology/IT limitations (multiple conflicting legacy systems)
- Regulatory requirements (unclear or changing)
- Product-specific requirements (translated into unique tasks and deliverables)
- Program priority (due to commercial/business reasons)
- Unexpected internal/external events (leading to change in resources and course of action)

Most of such factors were categorical and attribute variables that were rarely operationally defined and hard to quantify. Given the poor data available for the few dozen programs, statistical analyses typically required in Analyze were not possible. For each program, a different set of factors seemed to contribute to cycle time. There was hardly any Pareto effect or consensus on the critical few drivers. What could the team do to verify the relative impact of the factors and prioritize them for improvement?

Entering the Improve phase without a clear focus on a few critical factors, the team brainstormed and developed an assortment of solutions to address various causes. Eliminating various types of waste led to a number of proposed changes. Implementing automation to replace manual work was a popular high-impact solution but required capital investment and long-term planning. A final recommendation was to identify best practices and incorporate them into a global process as the future state. Process maps, responsibility matrices, guidance documents and templates were proposed to guide the functions involved. During the implementation, a practical question then arose: to what extent should we standardize or prescribe the solution without being seen as over-controlling or bureaucratic? In an organization where the term "process" was often viewed as a rigid structure that stifled innovation and individual creativity, how can the process be efficient, consistent, but also flexible and enabling? The team knew that ownership and change management would be a big issue in the Control phase.

The improvement project did not end with implementation, even with sustained ownership of the solutions. Despite visible process changes, new roles and responsibilities, training of staff, and a wide array of tools and templates, senior management's question remained: "How can we be sure that the new process is better, and by how much? Can you assure us we will beat the competition?" Given the numerous changes happening outside the project and many factors (from known and controllable to unknown and uncontrollable) that could influence the cycle time, the team saw no single factor that could be a useful leading indicator. Since it would take at least two years to have one project go through the new process and many more years to establish a new baseline, the team was struggling to provide a convincing answer. In the meantime, R&D program managers asked: "How much could the new process improve MY program's cycle time?" Improvement in the average did not matter to them because each program was so unique. Without a clear path forward, senior leadership reluctantly declared project success so they could dissolve the team to free up resources, but promised to "study the issue further."

As the example shows, even a well prepared OpEx team with strong leadership support faces serious challenges when it comes to tackling process improvements in an R&D environment. In reality, the situation is often worse because most R&D organizations exhibit a low level of OpEx maturity: poorly defined problems, lack of sponsorship, project variability, and inexperienced teams. But what is really unique about improving pharmaceutical R&D processes? How should OpEx professionals approach it?

3 Challenging assumptions: Pharmaceutical R&D is different

To create a right mindset when approaching the R&D process improvement challenge, it is helpful to revisit two unquestioned assumptions we carry over from improving manufacturing or services.

Assumption 1: Variation is always undesirable. This is not the case in R&D. The output of the pharmaceutical R&D process is a new medicine, whose ideal characteristics are often defined by the Target Product Profile. The path to achieve that goal is much less defined at the beginning. The process involves numerous decisions along the way, e.g. choices among multiple biological pathways, mechanisms, or formulations. The decision to investigate or pursue one way or the other depends on the experience and human judgment of the knowledge workers. Some observed variability simply reflects the freedom given to the teams to design their own work and to innovate. Additional variation among projects is due to scientific or business reasons. For example, the therapeutic area influences the design and duration of a clinical investigation, and portfolio priority leads to varying levels of resource allocation among projects. The challenge is to identify and separate sources of intentional variation from those undesirable, such as irreproducible results and inconsistent project planning.

Assumption 2: The process, not the people, contributes predominately to the quality and performance. Because the work is defined and executed by a team of experts in R&D, "people are the process." While a large amount of work in R&D is routine and can be organized and managed as a process, significant progress and innovation come from people working together as a self-organizing team. People familiar with team dynamics understand the challenge of working with cross-functional, multi-cultural, and multi-regional teams. Team leaders and senior management need to understand the factors that build an effective team, e.g. commitment to goals, clear roles and responsibilities, established trust and agreed collaborative processes. In addition, multiple teams are involved along the process from early discovery to commercialization, and ownership continuity and knowledge transfer are largely facilitated by people. Selecting the right teams and enabling them to effectively bring out innovation is not a process issue – it requires proper organization design, effective governance, a supportive culture, individual and team accountability, and continued development of people. An overemphasis on process can limit our ability to see broader issues and opportunities that related to the organization, people and culture, and therefore not engaging the right stakeholders, e.g. senior leadership.

In the hypothetical example above, the team failed to understand the sources of the variability in R&D, and approached the problem as if all observed variation was the characteristics of the process, i.e. "common cause" variation. In reality, the largest contributor is "special cause" variation, e.g. decisions and circumstances that are unique to individual programs and teams. Furthermore, the team treated the process as a manufacturing or transactional process and failed to recognize there was a large governance component in the long cycle time.

If a traditional process-focused improvement effort was not enough, how could they have done it differently?

First, there are a few concepts that are fundamental to our understanding of pharmaceutical R&D productivity.

1. R&D is largely knowledge work in which a considerable number of tasks cannot be well defined. Peter Drucker raised "knowledge-worker productivity" as a management challenge in the 21st century and laid out the six major factors that differentiate knowledge-worker from manual-worker productivity (Drucker, 1999). Traditional process-focused improvement methods were developed primarily for manual work and have a basic assumption: most if not all tasks can be pre-defined in a process in order to produce the desired outcome. Consequently, we expect the process to vary within a definable range. In other words, it should be stable. To improve manual-worker productivity, the question is about "how." This is true in manufacturing or services. However, in knowledge work, such as in R&D, the crucial question is about "what" because all tasks are not known in advance. A substantial amount of tasks are progressively planned, defined and executed by the knowledge workers themselves (individually or in collaboration). It is important to appreciate the emergent nature of R&D, in which new scientific and market information continues to emerge and modify the subsequent activities.

2. A process has to be purposely designed - "fit for use." A process in R&D should enable knowl-

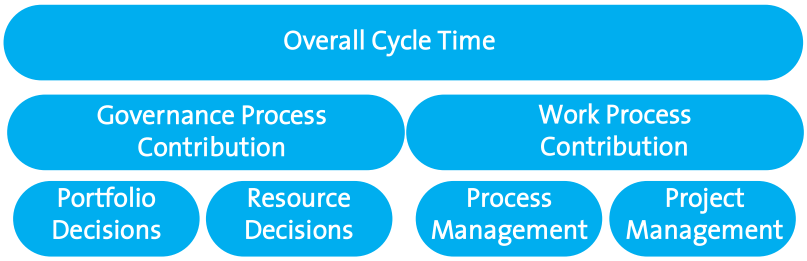
edge work productivity, e.g. enabling close collaboration and effective communication. The resistance against "processes" in R&D often comes from the perception that a process limits intellectual freedom. When designing or changing a process in R&D, we have to strike a careful balance between implementing best practices and encouraging creativity. Choosing the right processes to improve and designing to the right level of details become critical.

3. Governance and work processes jointly contribute to R&D productivity. Governance processes determine what is done, and work processes describe how things are done. A governance process helps management establish priorities and make critical decisions regarding project portfolio and resources allocation in order to achieve optimal results. A work process represents how resources (human and non-human) are organized, based on the current knowledge and practices, to produce a pre-specified outcome. While the work processes are typical targets for improvement by OpEx practitioners, the governance processes are often the bottlenecks in R&D productivity. A different approach is required to address governance processes.

Back to our example, the team could separate the governance layer of the overall process from the operational layer, and analyze them differently. Much of observed cycle time variation was likely due to portfolio and resource decisions, i.e. how many projects in the portfolio and how many resources allocated to each project, made by the executives or governance body (see Figure 2). It would be a waste of time trying to understand why low priority projects with fewer resources took longer to complete – the time-resources relationship was known when the resource decision was made. These decisions do not change the operational level detail of the work, i.e. the work process. To reduce the overall cycle time, the management could follow Little's law, which states that the average cycle time is proportional to the number of items in the process ("work-in-progress" or WIP) and inversely proportional to the throughput. In the case of pharmaceutical product development process, any project, whether it is active, pending, on-hold or even discontinued, is a WIP item as long as it consumes organizational resources. It is common that projects in the portfolio stop moving while the teams wait for management decisions on resources or directions. Therefore, the obvious improvement opportunities at the governance level include 1) reduce the number of projects in the portfolio and 2) simplify decision making along the critical path to allow continuous flow. The former requires disciplined portfolio management, and the latter requires the management to see themselves as servant leaders, not as authorities.

Second, the team could use the approach for managing special cause variation, i.e. identify and understand outliers. At the core of Operational Excellence is identification and separation of sources of variation. This is true and applicable in pharmaceutical R&D. But the sources in pharmaceutical R&D are much less obvious than in manufacturing or services. Instead of looking for a "process" baseline (i.e. average cycle time of the process), it would be more productive to investigate if a "project" baseline (i.e. the initial project plan) was created for each project. They could estimate the amount of variation among project baselines that reflected intentional or assignable variation, i.e. their portfolio priority and scientific rationale. The remaining variation could be attributed to two sources: 1) process inconsistency and 2) deviations in project execution. If of a significant size, each source would be opportunities for focused improvement with traditional OpEx tools and methods. By developing greater appreciation of the nature of knowledge-based work and the roles of governance and work processes in pharmaceutical R&D, we can start to see new opportunities beyond the process.

Figure 2 Governance and work processes contribute to cycle time.



4 An Opportunity: Process and Project Management

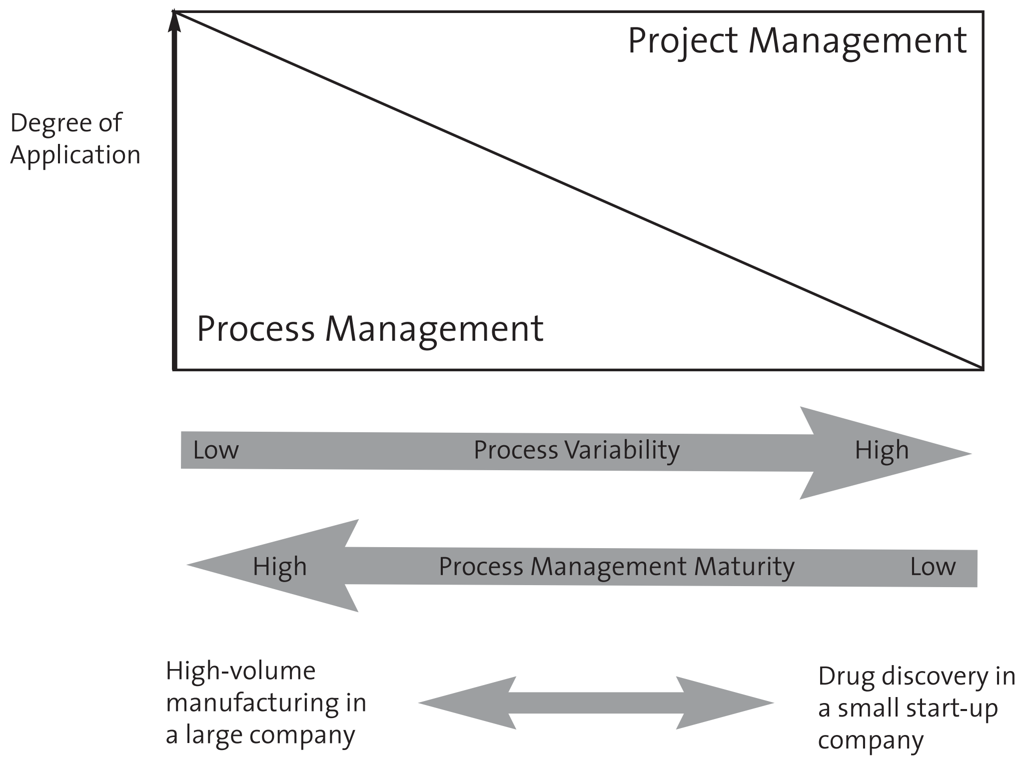
Operational Excellence is more than a set of tools. It is a culture of continuous improvement that requires commitment and engagement at all levels across the organization. In manufacturing and services where processes are more defined, process management (with its roots in the PDCA cycle) has proven to be an effective mechanism to engage the right stakeholders in continuous improvement. Given the unique nature of pharmaceutical R&D, how can OpEx practitioners use process management effectively?

In pharmaceutical R&D, many activities change due to unique requirements of the projects or rapid advancement of knowledge and technology. Therefore, activities are more project- than process-driven. By Project Management Institute definition, a project is "a temporary endeavor undertaken to create a unique product, service, or result." (PMI, 2013) Most of the pharmaceutical R&D activities fit this definition. Process management is useful only to the extent the activities are repeated, whereas project management capabilities are specifically developed to address the unique nature of a project.

Project management has evolved as a discipline in the past decade. As it becomes an essential part of product development and technology implementation in many industries, it has incorporated a wide range of management best practices, including Operational Excellence concepts and tools. Unfortunately, in most organizations inexperienced staff performs project management work. Too often, management and staff equate project management to "Gantt chart" management, i.e. creating and updating project schedules on a Gantt chart. Instead of proactively and methodically managing various aspects of a project, these project managers take orders from management, record meeting minutes, update the Gantt charts, and track down late tasks. In our view, project management goes beyond the standard scope, time, and cost management. It systematically integrates these aspects with quality, risk, communications, procurement, and stakeholder management required in a project lifecycle (PMI, 2013). The principle of progressive elaboration is particularly applicable to the emergent nature of R&D, and its emphasis on iterative planning and lessons learned is consistent with the PDCA cycle in Operational Excellence.

One advantage of strengthening project management is that its implementation immediately

Figure 3 Combining process and project management for continuous improvement.

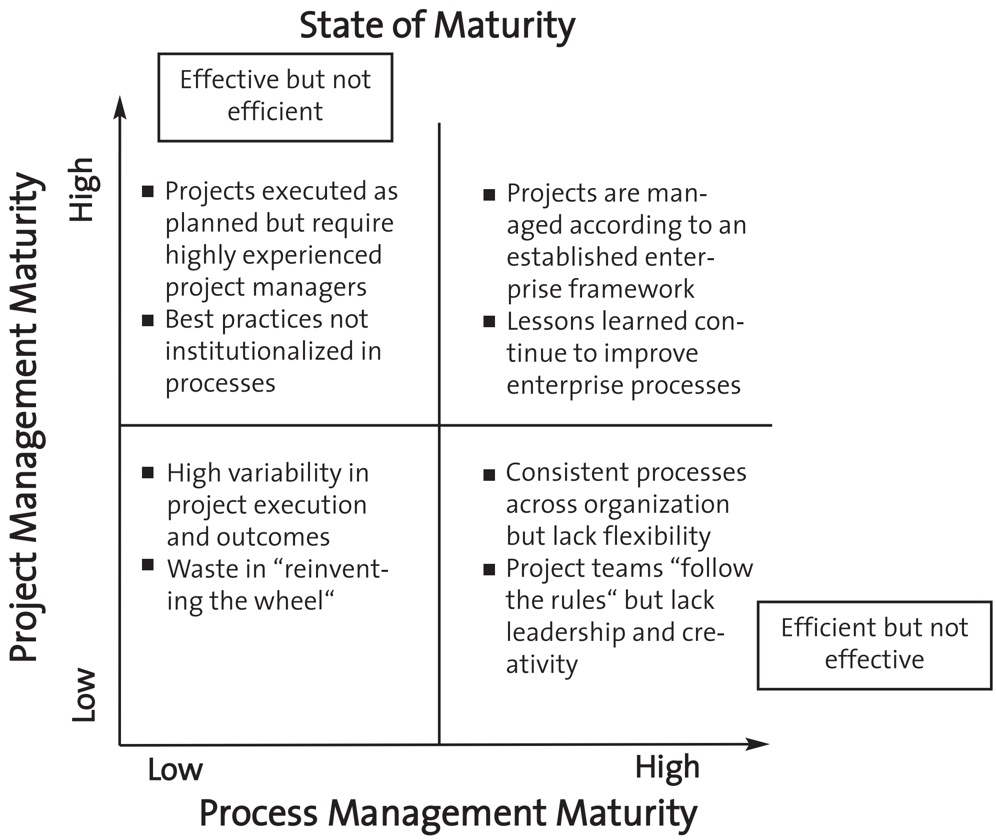


benefits the current business. Another advantage is its real-time monitoring of project metrics, such as deviations from the plan using earned value, which can be leading indicators of process performance. In addition, there is a growing acceptance of project management in the pharmaceutical R&D organizations as scientists as well as management recognize its benefits. Therefore, there exists a great opportunity for OpEx practitioners working in this industry to leverage this body of knowledge and organizational capability for improvement.

As a first step, OpEx practitioners have to see the problems from both project and process perspectives. Process management and project management can be combined to different degrees depending on the variability of the process and organization's process management maturity (see Figure 3). For example, in a typical high-volume manufacturer where low process variability is desired, process management is most critical in the pursuit of continuous improvement. As process management is developed and matured, process variability goes down and quality and productivity go up. In the case of pharmaceutical R&D, the discovery phases have less defined processes than early and late development phases. Therefore, process management has been limited to routine activities or at a high level in discovery, but adapted more broadly in late development processes. Research and development activities in all phases heavily depend on project management. So improvement in project management capabilities will have the biggest impact on R&D productivity.

To determine the best improvement approach, it is helpful to assess the organizational maturity in two dimensions: process management and project management, as illustrated at high level in Figure 4. For example, a R&D organization with high project management maturity but low process management maturity may be able to execute projects successfully but only with highly experienced project managers and teams. The capability is not readily scalable if the demand rises because the best practices have not been institutionalized in the form of processes. In contrast, an organization with high process maturity and low project management maturity may be efficient delivering standard or routine results. But if the external circumstances demand different outcomes, the organization may not have the right leaders and culture

Figure 4 Process and project management maturity assessment.



to respond quickly. OpEx practitioners and senior management should use this maturity assessment with their business strategy to determine the desired future state for the organization, and then identify the optimal path (see Figure 5).

Based on our experience, there is a greater organization capability in project management than process management in pharmaceutical R&D. In such a case, the organization's project management capability should be leveraged by OpEx practitioners, i.e. project management can be a temporary substitute for process management, providing an alternative path to improved business results until the organization becomes ready to embrace full process management. The same maturity assessment can also help other R&D organizations, such as those in the medical device industry, where both process and project management have a medium level of maturity. OpEx practitioners improving R&D processes should consider the following steps.

1. Assess organizational maturity in process management and project management

2. Understand what is common among R&D projects and what is unique

3. According to the organizational maturity, apply process management to standardize the common tasks as processes, and apply project management to manage unique tasks in projects, respectively

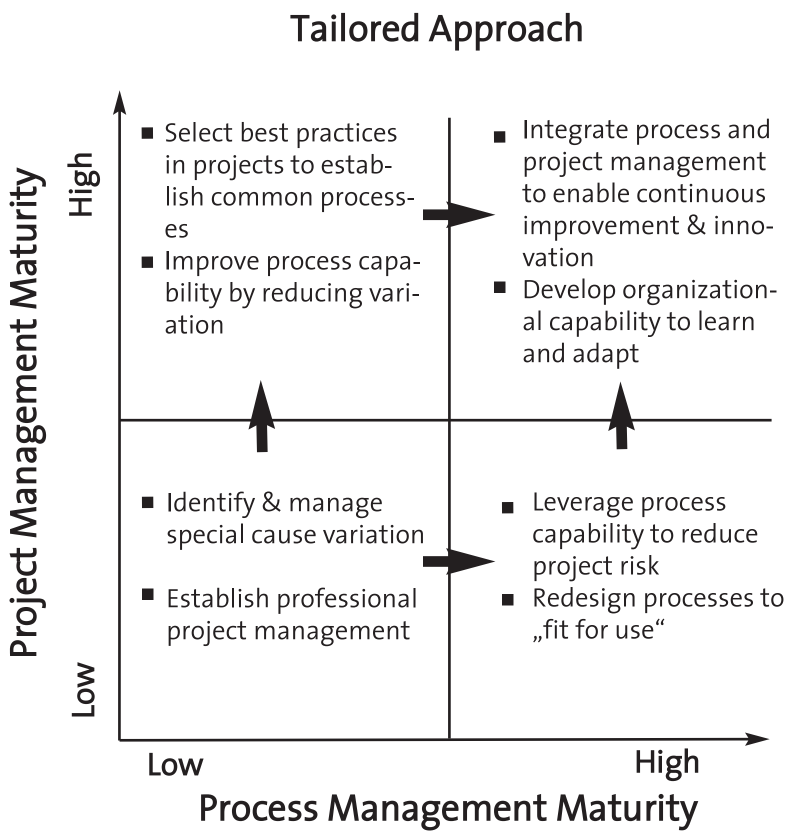
4. Build project plans based on governance decisions, standardized work processes, and expertise of the teams

5. In real time, use lessons learned during project execution as feedback to continuously improve existing processes

6. Continue to improve process and project management capabilities in the organization

Figure 6 shows how governance, project management, and process management work together to ensure project success and continuous improvement.

Figure 5 Tailored approach based on process and project maturity.



5 Conclusion

In summary, improving pharmaceutical R&D using classical process-focused approaches are unlikely to succeed without adaptation to its unique environment. The emergent nature of R&D and knowledge-based work mean that R&D processes are less defined and highly variable. Governance, organizational structure and capability have significant impact on R&D productivity. Operational Excellence practitioners using the traditional approach need to look beyond the process and question long-held assumptions. One opportunity to overcome some of these challenges is to integrate project management with the Operational Excellence methods that do apply. By carefully balancing project management and process management in our approach to R&D productivity, we can continually reduce variation over the long term while improving business results from on-going R&D projects. The effectiveness of this approach will impact not only R&D productivity but also culture change required for continuous improvement by embedding the PDCA mindset in everyday activities at all levels of the organization.

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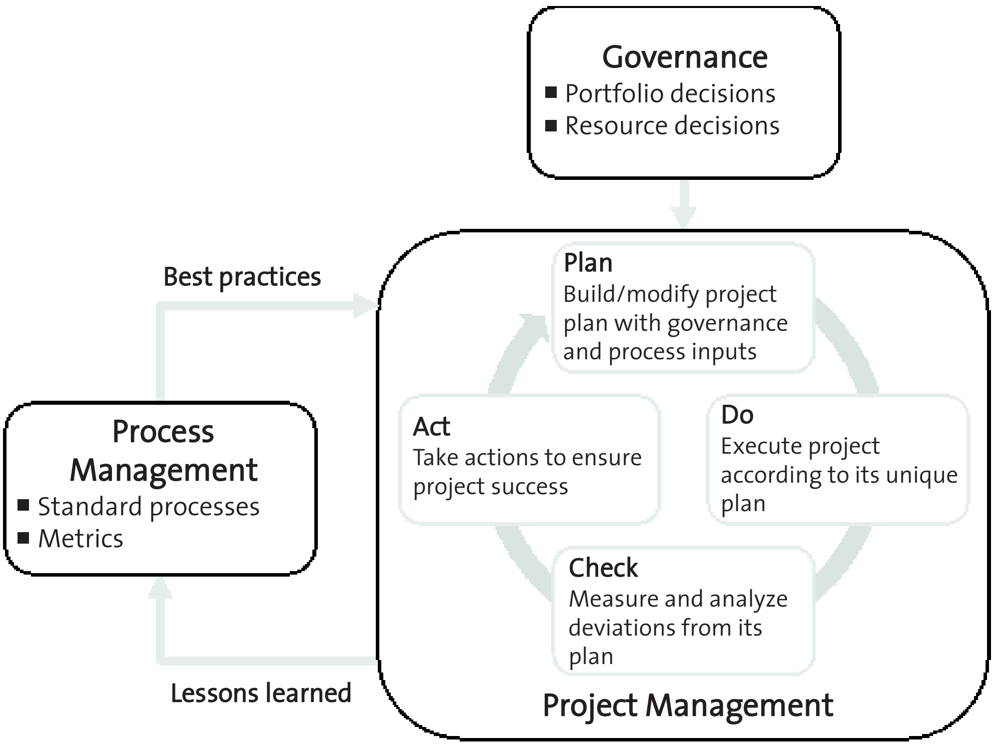
References

Barnhart, T.M. (2013): *Creating a Lean R&D System*, Taylor & Francis Group, Boca Raton, Florida.

Bertels, T. (ed.) (2003): *Rath & Strong Six Sigma Leadership handbook*, John Wiley & Sons, Inc. Hoboken, New Jersey.

Cockburn, I.M., (2007): Is the Pharmaceutical Indus-

Figure 6 Integrated process and project management ensures execution and continuous improvement.



try in a Productivity Crisis? In Innovation Policy and the Economy, *National Bureau of Economic Research*, Lerner J. and Stern S. Ed. Volume **7**, pp.1-32.

Deming, W.E. (1986): *Out of the Crisis*, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Drucker, P.F. (1999): *Management Challenges for the 21st Century*, HarperCollins, New York, pp. 133-159.

Johnstone, C., Pairaudeau, G., and Pettersson, J.A. (2011): Creativity, innovation and lean sigma: a controversial combination? *Drug Discovery Today* **16** (1/2), pp. 50-57.

Mestre-Ferrandiz, J., Sussex, J., and Towse, A. (2012): *The R&D Cost of a New Medicine*, Office of Health Economics, London.

PhRMA - Pharmaceutical Research and Manufacturers of America (2013): *2013 Pharmaceutical Industry Profile, Washington.*

PMI (2013): *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*, fifth edition, Project Management Institute, Inc., Newtown Square, Pennsylvania.

Scannell, J.W., Blankley, A., Boldon, H., and Warrington, B. (2012): Diagnosing the decline in pharmaceutical R&D efficiency. *Nature Reviews Drug Discovery* **11**, 191-200.

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Practitioner's Section

Bioplastics Tipping Point: drop-in or non-drop-in?

Fabio De Almeida Oroski*, Flávia Chaves Alves** and José Vitor Bomtempo***

* School of Chemistry/ Universidade Federal do Rio de Janeiro (UFRJ), Technology Centre, Bloco E, Ilha do Fundão, Rio de Janeiro, 21941-909, RJ, Brazil, oroski@eq.ufrj.br

** School of Chemistry/ Universidade Federal do Rio de Janeiro (UFRJ), Brazil, falves@eq.ufrj.br

*** School of Chemistry/ Institute of Economy/Universidade Federal do Rio de Janeiro (UFRJ), Brazil, vitor@eq.ufrj.br

The forecasted bioplastic production capacity has signaled a strong growth in the next years, but with higher participation of drop-ins. Drop-in bioplastics are non-biodegradable materials, identical to their fossil counterparts although obtained from renewable raw materials. The present paper examines why drop-ins have presented growth rates higher than non-drop-ins, analyzing some critical factors of their adoption by end users and whether the bioplastics tipping point has been reached. This comparison between drop-in and non-drop-in bioplastic innovation dynamics, which involves investment and complementary assets, will contribute to a better understanding of the critical factors that lead to bioplastics tipping point.

1 Introduction

Currently, there is a growing interest on bioplastics development encompassing both innovative products and production processes. Bioplastic production is favored as an alternative solution to the use of oil as raw material, and also because of the demand of products which generate a smaller environmental footprint. Bioplastics are polymers obtained from biomass, renewable raw materials such as: corn, sugar cane, beet, cellulose, waste and others. They are alternative materials to the conventional plastics obtained from fossil raw materials.

Recently it is being discussed whether the bioplastics have reached the so-called tipping point. The tipping point achievement occurs when high adoption rates are observed in a very short time, similar to an epidemics outbreak (Gladwell, 2000). Some experts argue that the accumulation of resources and skills used in the development of these products associated to the high number of companies involved sets a critical condition for the outbreak of the tipping point (ICIS, 2012).

Bioplastics are biobased and can be biodegradable or non-biodegradable (Table 1). When degradation is caused by biological activity, especially by the enzymatic action of microorganisms, it is called biodegradation. The process of biodegradation depends on the environmental conditions (e.g. location or temperature) and on the material itself. Therefore, the biodegradability of a plastic material is not dependent only on the source of raw material. 100 percent renewably sourced materials can be entirely resistant to biodegradation. Similarly, fossil-based plastics can be biodegradable (European Bioplastics Association, 2012).

Bioplastics production capacity in 2011 was around 1.1 million tonnes, representing less than 1% of the global production capacity of conventional plastics. Despite its low market share, it is forecasted that the production will grow to nearly 6 million tonnes by 2016 (European Bioplastics Association, 2012), which represents an annual growth of 31%. This means that current capacity will have a fivefold growth within five years (Figure 1).

The strongest area of growth is expected to be non-biodegradable products, such as biobased polyethylene terephthalate (PET) and polyethylene (PE), among the drop-in solutions. The term drop-in was initially used for biofuels which specifications allow their market application with existing infrastructure and no relevant investments in specific assets. In this context, drop-in plastics are non-biodegradable materials, obtained from renewable raw materials that present identical technical properties to their fossil counterparts. Drop-in solutions represent the single largest sector of the global bioplastics production. They are (partly) biobased, non-biodegradable commodity plastics such as PE, PET, or PP, and can be easily recycled along their conventional counterparts. While drop-ins are well known by market, non-drop-in plastics are different and alternative materials, generally applied to niches due to specific properties. The inclusion of drop-in bioplastics in the forecasted global bioplastics production capacity is due to the recent announcement of their development and production with active participation of the end users as investors and/or adopters. The end users are companies that buy manufactured plastics, mostly packaging materials, including also the industries of consumer goods, personal care, cleaning materials, toys, retail, etc.

The main objective of this paper is to discuss the reasons that lead to a higher participation of drop-in materials rather than non-drop-in in the forecasted bioplastics production and the decisive role of the end users. To this end, we will analyze two bioplastic examples: the first, polylactic acid (PLA), non-drop-in, which has been commercially produced by Natureworks (140,000 tonnes/year) and the second, green polyethylene (green PE), drop in, produced by Braskem in a Brazil-based facility with production capacity of 200,000 tonnes/ year. PLA and green PE examples were chosen because they are under commercial production and both have strong representation in the current and future demand of bioplastics. Other important players in the PLA development are Purac (acid lactic producer) with a plant of 75,000 tonnes/year and Futerro, a joint venture between Galactic (lactic acid producer) and Total (oil and petrochemical company), but without commercial production (European Bioplastics Association, 2012).

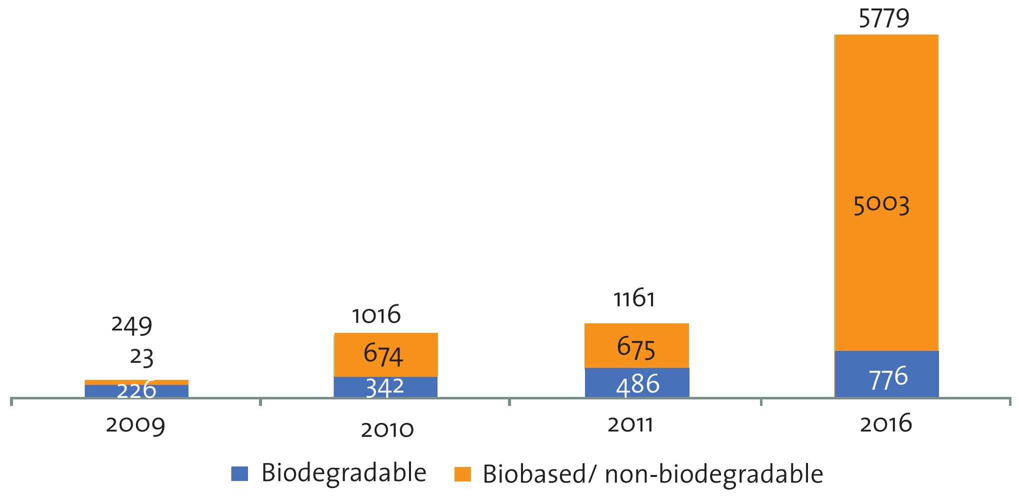
2 Drop-in Participation in bioplastics tipping point

European Bioplastics Association has forecast-

Table 1 Examples of plastics by source and biodegradability.

Biobased, biodegradable PLA (polylactic acid)	**Biobased, non-biodegradable** Green-PE (green polyethylene)
Fossil-based, biodegradable PBS (polybutylene succinate)	**Fossil-based, non-biodegradable** PE (polyethylene)

Figure 1 Bioplastics Production Capacity by type - Kton/year (European Bioplastics Association, 2012).



ed that drop-in materials will represent 86% of the global bioplastics production capacity by 2016 (European Bioplastics Association, 2012) with especial participation of green PET and green PE, as shown in Figure 2. Green PET alone will respond for 80% of the forecasted capacity, driven by the significant demand for bottle manufacturing, which shows the important role of the end users in the bioplastics adoption process. Two giants in the beverage soft drink industry have already been using PET which accounts for up to 30% of renewable content. Green PET (named as bio-PET 30 in the graphic) is produced from monoethylene glycol (MEG) obtained from biomass (ICIS, 2012).

It is important to highlight some elements that have contributed for the greater participation of drop- in materials:

(a) their use represents a small risk for end users, because their technical properties and manufacturing processes are already known by the value chain

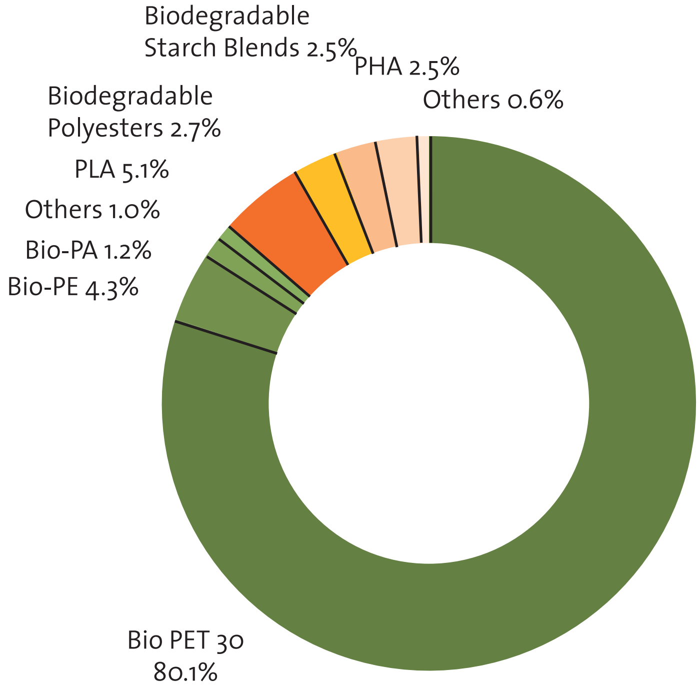
(b) it is not necessary to adjust the plastic manufacturing machinery, reducing investment and generating lower switching costs for processors and end users, because it does not require new specialized complementary assets

(c) lower recycling impact, because these materials are not depicted as contaminants in the recycling of conventional plastics.

Due to the above mentioned reasons, it is expected that the drop-in materials adoption will take less time than the adoption of non-drop-in ones. However, drop-ins are not biodegradable. It is important to ask then: what is more important for end users as value proposition: biodegradability or the source of the material? Additionally, some end users have signaled that bioplastic adoption does not depend only on those factors. Life cycle assessment (LCA) and cost are also important factors taken into consideration. Biodegradable materials may not be suitable from the environmental point of view if their production and purification processes consume high amount of water and energy.

Some years ago, the polylactic acid (PLA), biodegradable non-drop-in material, was mentioned by companies, researchers and market experts as one of the bioplastics most likely to succeed. In 1997 the project Dow Cargill was announced. It consisted of a joint venture between the Dow Company, one of the largest petrochemical companies, producing conventional plastics and Cargill Company, a leader in agribusiness and food production giving birth to Natureworks, which

Figure 2 Bioplastics Production Capacity in 2016 by type (European Bioplastics Association, 2012).



promised to bring into the market high volumes of the first biodegradable plastic in a very short time (Brito et al., 2011). PLA, produced by polymerization of lactic acid obtained via fermentation of carbohydrates, is an apparently promising plastic, but although its market has grown, it still did not reach an expressive volume with demand remaining below expectations (Chemical Week, 2011).

Drop-in green PE trajectory shows different signals compared to PLA. The commercial production of this product obtained from sugarcane ethanol started in 2010 and several end users (e.g.: Johnson & Johnson, Nestle, Toyota, Danone, P&G) have adopted it (Braskem, 2012a). It is believed that much of its production is already compromised through commercial agreements and contracts (Braskem, 2012b). Braskem strategy was to get closer to end users in order to avoid the risk of the material being sold as conventional polyethylene. Another important point is observability (Rogers, 2003), which measures the degree to which the results of an innovation are observable to other potential users. The easier the perception of the new technology adoption process, the higher will be the diffusion speed among other users.

Concerning biomass utilization at an industrial scale, apart from availability, other determining factors such transport and storage should be considered due to the large amounts of materials required. (Frohling et al., 2011). Regions such as Brazil, United States, China, India, Thailand and others countries, which produce large quantities and different varieties of biomass feedstock under favorable climate conditions, offer good conditions for biofuels and bioprodutcs production. Therefore, these countries could be seen as strong candidates to receive investments in bioplastics production (DOE Biomass Program, 2005; IEA, 2011; Iles and Martin, 2013).

3 Critical Factors for PLA (biodegradable, non-drop in) and Green PE (non-biodegradable, drop-in) adoption by end users

In this section, some factors frequently pointed out as critical on new product adoption (Rogers, 2003; Porter, 1980) are explored to discuss the role of end users in the bioplastics development, considering if the new material is a drop-in or non-drop-in solution. Three critical factors for the adoption of PLA (non-drop-in) and green PE (drop-in) - technical and process properties, end user switching cost and impact on recycling and life cycle assessment (LCA) - are described below.

3.1 Technical and process properties

The adoption of a new material certainly depends on end user perception of its technical advantages (Rogers, 2003), which, in this case, favors the drop-in solution green PE, because it presents identical properties compared to its conventional counterpart. PLA appears as a “new” product to be explored and presents some inadequate properties for some applications, as for example, low crystallization rate, low resistance to impact, and low thermal resistance. However, these properties can be improved using additives (Brito et al., 2011).

The complementors players (Nalebuff e Brandeburger, 1995), that do not produce the resin, but are inserted in the production chain, mainly as blends and additives suppliers, have become strategic to improve products and fill in important gaps in the new applications development and improvement of current ones.

A good illustration of complementors role in a plastic development was observed in the polypropylene (PP) trajectory. Initially, the product had presented limited technical properties narrowing market applications. Its production process was complex and inefficient involving four steps. However, new additives and catalysts, improving technical and process properties, such as mechanical resistance and UV protection, allowed PP to spread to a wide range of applications. Besides product improvements, the production process advanced to only one step, reducing costs and transforming PP in one of the most produced resins in the world (Bomtempo, 1994; Landau, 1998).

Additive manufacturers are engaged in developing solutions for PLA chronic problems such as high susceptibility to degradation and loss of properties during processing. Some chemical companies and blend suppliers such as Cereplast, Natureplast, Polyone, Arkema, Sukano and others (Plastics Technology, 2011) are among current complementors in addition to traditional players such as Dow, Basf and Du Pont.

Biodegradability is interesting for some industrial sectors such as food market, but it does not constitute an advantage in itself, being necessary to add some other technical improvements. Companies leading with PLA are focusing on new additives and blends developments (Shen et al., 2009) to foster PLA use in semi-durable goods. An example is PLA use in smartphones developed by Dandelion Research Ltd from Hong Kong, formed by 90% Natureworks (Ingeo) PLA blend with 10% of other non-fossil materials (Plastics Technology, 2011).

PLA and its production process have improved over the last fifteen years, since the beginning of the Dow Cargill Project in 1997, as indicated by the emergence of a second generation of PLA. This generation was developed by Purac Company, a global leader in lactic acid, the main raw material for PLA production, which improved some of the product characteristics. The efforts focused on reducing the number of the production steps and improving material´s quality, such as higher thermal resistance, which can enable new possibilities for PLA use (Purac, 2012).

3.2 End User Switching Costs

The main end user switching costs (Porter, 1980), when considering the substitution of a known conventional plastic by a non-drop-in material are: (a) increased dependence on supply, frequently represented by a single producer, which reduces the flexibility of a possible change of supplier, (b) investment in specific assets (Teece, 1986) and (c) learning time (Leonard-Barton, 1995).

Unlike conventional polymers, the new materials require an effort from manufacturers and users to learn about their properties and develop applications. Very likely, it will demand that suppliers develop new machinery, equipment and additives. Thus, it is necessary to promote attraction and mobilization efforts of those agents in order to create an innovation agenda that encourages the non-drop-ins development.

Plastics conversion generally involves specific machines that represent significant costs for converters. When an important end user adopts the new material, major security is perceived by the market. When more companies adopt a new material, the greater is the interest in developing solutions to reduce end user switching costs. A good practice example of end user influence on adoption was the introduction of PET bottle in the soft drink industry. In the eighties, two liter PET plastic bottle was introduced by Coca-Cola, changing the pattern of packaging in the industry. Therefore, PET has become one of the most important resins in beverage industry (Coca-Cola, 2012b; Food and Beverage Packaging, 2009).

Some factors mean high end user switching costs for PLA adoption. Current PLA production process involves obtaining lactide, the monomer produced from lactic acid. Lactic acid is the result of sugar fermentation and represents around 80% of the variable cost of PLA production, thus PLA may be considered a sugar in polymer form (Wolf, 2005). Strong sugar price fluctuations (Indexmundi, 2012) has been an obstacle to the creation of a favorable environment to PLA adoption, since one of its appeals would be to escape from the instability observed in conventional plastics which follow oil prices. However, this risk is reduced in the case of drop-ins because the cost of reversing the use to conventional polymer is smaller since they present identical properties.

PLA adoption by manufacturers implies in changes or adjustments of machinery and consequently in investment and training, increasing the end user switching costs. The learning time also contributes to increase the new users' risk perception (Rogers, 2003).

Green PE adoption seems to be a process quite different when compared to PLA. Braskem, as a major polymer manufacturer, has accumulated technological expertise in the production of conventional PE, and accesses its own research and development (R&D) structure to develop applications, which facilitates the interaction with converters and end users. The green PE business model presents significant economy of scope, because it is within a conventional PE manufacturing organization that has complementary assets of administration, logistics and application R&D. Thus, when drop-ins are produced by the same conventional polymer manufacturer its development will be facilitated by the presence of the complementary assets.

It is important to note that the insertion of green PE into the market was facilitated, because its technical properties were already widely known by end users and complementors, once for many decades polyethylenes have been the thermoplastics with higher demand (Shen et al., 2009). From Braskem point of view, the greatest changes occurred on raw material supply due to specific logistics infrastructure and assets of ethanol. Regarding to end users, the company has promoted adjustments over its marketing and sales structure, as the formation of dedicated sale and technical assistance teams (Braskem, 2012b).

3.3 Impact on Recycling and life cycle assessment (LCA)

The development of an industrial recycling infrastructure is regarded as an important pre-condition for bioplastic market. The current recycling systems were developed to identify and process conventional plastics, such as PET, PP and PE and therefore, non-drop-in bioplastics, such as PLA, can be seen as contaminants. For example, PLA requires specific composting conditions (temperature and humidity) to degrade within several months and appropriate collection, sorting and composting systems must be employed to decompose. Although current capacity of PLA does not have enough scale yet to stimulate its recycling (Jim Jem et al., 2010), one initiative called LOOPLA, led by Galactic with other companies related to PLA, such as Nature-

works, promises lactic acid recovery from post-consumer PLA employing depolymerization process (LOOPLA, 2013).
Other important question to be considered is the life cycle assessment (LCA). A perspective for bioprocess progress is the so-called "process intensification" which focuses on the development of processes with the smallest environmental footprint (Sanders et al, 2012). The environmental performance and production cost of lactic acid can be improved with new processes using membranes (Pal P. et al., 2009), reducing PLA environmental footprint and production costs throughout the reduction of high levels of water and energy consumption in the current purification process.
Currently, the industry is using additives to increase the life time and enable other PLA applications (Plastics Technology, 2011). Thus, the biodegradability concept, which could encourage greater utilization of this material, was partially abandoned. An effort to approach the environmental issue from other ways in order to emphasize the PLA advantages has been observed (Plastics Today, 2009). The use of LCA as a tool to measure the product sustainability and identify process steps that can be improved shows the major players' interest to enhance PLA competitive advantage in relation to the environment. According to Braskem, green PE presents LCA advantages when compared to the conventional polyethylene. Green PE captures 2.5 tonnes of CO_2 per tonne of product, which, together with social aspects of sugarcane production, is a requirement from end users (Braskem, 2012a).
The factors analyzed above (summarized in Table 2) can indicate a relative very short time horizon for green PE being "perceived" and adopted by the market (Braskem, 2012b).

4 Conclusions

This article explored the bioplastics development in a context of transition for more participation of renewable resources in economy. This scenario is composed by many drivers, such as oil prices and fossil raw material dependence, environmental and technological issues, biomass availability, regional legislation and infrastructure, non-fossil raw materials costs and availability (Sanders and Langeveld, 2010; IEA, 2007). These drivers should be identified to allow actors to understand the development process and to prioritize actions and strategies. Players from different industries and knowledge basis participate in bioplastics development (Shen et al, 2009). Some examples are: petrochemicals and chemicals companies (e.g.: Dow, Braskem, Du Pont, DSM, Basf), agribusiness and/or ingredients and food companies (e.g.: Cargill, Purac, Galactic) and end users (e.g.: Coca-Cola, Pepsi, Walmart, P&G, Toyota). Among them, we outline the end users role in adoption of drop-ins and non-drop-ins solutions. Their perspective has pointed out critical factors explored in this article.

Three critical aspects of bioplastics adoption by end users were analyzed: technical properties and processing, switching cost and the impact on recycling and LCA. Significant progress in bioprocesses and bioproducts are forecasted, such as better technical properties and processability and small-

Table 2 Critical adoption factors for PLA (non-drop-in) and green PE (drop-in).

CRITICAL FACTORS	PLA (NON DROP-IN)	GREEN PE (DROP-IN)
Technical and processing properties	Require efforts to improve the process (cost reduction) and the product (material properties improvement).	Known and mastered from technical skills accumulation.
End user switching costs	Greater investments in specific assets on the supply and demand sides.	Smaller investments in specific assets based in the supply side.
Impact on recycling and LCA	Greater impact on recycling. Need to analyze LCA.	No impact on recycling. Need to analyze LCA.

er environmental footprint, which will certainly increase the non-drop-in materials competitiveness. The end user switching costs, directly proportional to the need of investment for material adoption, reflects the acquisition or adjustments costs of complementary specialized assets. Drop-ins require investment concentrated on the supply side, related to the supply and logistics of new raw materials. Non-drop-ins require investments in specific assets on both supply (feedstock) and demand (processors and end users) sides.

It should be enhanced the decisive role of the end users on the selection of the bioplastics that will be produced and adopted by the market. Coca-Cola has recently announced cooperation with Gevo, Virent and Avantium, companies linked to bioproducts and bioprocesses, in order to develop renewable alternatives for PET, illustrating the strategic position of end users in shaping the bioplastics future. This strategic position is very clear in the case of Coca-Cola. From the three projects the company is supporting, two (Gevo and Virent) which aim at the production of a renewable PET from a renewable para-xylene, so a drop-in plastic, and the third (Avantium) aims at developing a new material -PEF- as a non-drop-in PET substitute (Coca Cola, 2012b).

Finally, the greater drop-ins participation on the current stage of bioplastics trajectory can be explained by the smaller adoption barriers on the demand side, once the required investments are relatively low and converters and end users can use either conventional plastics as bioplastics, since both have the same properties. However, it is not possible to predict if drop-ins will have a greater participation than non-drop-ins in the long term. It should be noted that the greater participation of drop-ins is due to the maturity level of the bioplastics industry, still in its infancy, surrounded by uncertainties. Thus, agents tend to choose projects with smaller risks and faster execution. We believe that the conditions for a greater non-drop-ins participation, such as the increasing number of participants in the innovation agenda as complementors, knowledge accumulation and the vital end user participation on development projects are being created.

It is not clear that bioplastics have already reached its tipping point. But in recent years the introduction of drop-ins seems to have contributed to accelerate the bioplastics diffusion. Remains to understand how non-drop-ins can overcome the difficulties of the adoption process showed up now and contribute to the tipping point achievement and if the emerging bioplastics industry will be dominated by drop-ins in the future.

References

Bomtempo, J. V. (1994): I*nnovation et organization: le cas de l´industrie des polymères,* Doctorate thesis, École des Mines de Paris. Paris, France.

Brandenburger, A. M., Nalebuff, B. J. (1995): The right game: Use of game theory to shape strategy, *Harvard Business Review,* **73** (4) pp.57-81.

Braskem (2012a) : *Plástico Verde*, available at http://www.braskem.com.br/plasticoverde/, accessed 10 November 2012.

Braskem (2012b). *Interview with Antônio Morschbacker*, Innovation and Technology executive, held on 30 November 2012.

Brito, G. F., Agrawal, P., Araújo, E. M., Mélo, T.J.L. (2011): Biopolímeros, Polímeros Biodegradáveis e Polímeros Verdes, *Revista Eletrônica de Materiais e Processos*, **6** (2), pp. 127-139.

Chemical Week (2011): *Renewables*, available at http://www.chemweek.com/sections/cover_story/Renewables_34629.html, accessed 12 September 2012.

Coca Cola (2012a): *Coca-Cola bottles history*, available at http://www.coca-cola.co.uk/125/coca-cola-bottles-history.html, accessed 05 December 2012.

Coca Cola (2012b): *Coca Cola announces partnerships to develop commercial solutions for plastic bottles*, available at http://www.coca-colacompany.com/media-center/press-releases/the-coca-cola-company-announces-partnerships-to-develop-commercial-solutions-for-plastic-bottles-made-entirely-from-plants, accessed 05 December 2012.

DOE Biomass Program (2005): *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of A Billion-Ton Annual Supply*, available at http://www.eere.energy.gov/biomass/publications.html, accessed 20 July 2013.

European Bioplastics Association (2012): *Labelling, logos, charts*, available at http://en.european-bioplastics.org/press/press-pictures/labelling-logos-charts/, accessed 20 November 2012.

Food and Beverage Packaging (2009): *Timeline 50 years of packaging innovations*, available at http://www.foodandbeveragepackaging.com/articles/83980-timeline-50-years-of-packaging-innovations, accessed 05 December 2012.

Fröhling, M., Schweinle, J., Meyer, J.-C., Schultmann, F. (2011): *Logistics of Renewable Raw Materials*, in: Ulber, R., Sell, D., Hirth, T. (ed.), New Feedstocks for the Chemical Industry, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany.

Gladwell, M. (2000): *The tipping point: How little* *things can make a big difference*, Little, Brown and Co, New York.

ICIS (2012): *US biobased chemicals at a tipping point*, available at http://www.icis.com/blogs/green-chemicals/2012/09/us-bio-based-chemicals-at-a-tr.html, accessed 20 November 2012.

ICIS (2011): *Battle of the Bioplastics*, available at http://www.icis.com/blogs/green-chemicals/2011/03/battle-of-the-bioplastic-bottl.html, accessed 25 November 2012.

Indexmundi (2012): *Sugar Prices*, available at http://www.indexmundi.com/commodities/?commodity=sugar, accessed 10 December 2012.

IEA - International Energy Agency (2011): *Technology Roadmap: Biofuels for Transport*, available at http://www.iea.org/publications/freepublications/publication/biofuels_roadmap.pdf, accessed 20 July 2013.

IEA - International Energy Agency (2007): *Bioenergy Project Development and Biomass Supply*, available at http://www.iea.org/publications /freepublications/publication/biomass.pdf, accessed 20 July 2013.

Iles, A. , Martin, A. (2013): Expanding bioplastics production: sustainable business innovation in the chemical industry, *Journal of Cleaner Production*, **45**, pp. 38–49.

Jim Jem, K., van der Pol, J.F., de Vos, S. (2010): Microbial Lactic Acid, Its Polymer Poly(lactic acid) and Their Industrial Applications, *Plastics from Bacteria Microbiology Monographs* , **14**, pp. 323-346.

Landau, R. (1998): *The Process of Innovation in the Chemical Industry, in: Chemicals and long term growth: insights from chemical industry*, John Wiley & Sons, Inc, New York, pp. 162-179.

Leonard-Barton, D. (1995): *Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation*, Harvard Business School Press, Boston.

LOOPLA (2013): *Who we are?,* available at http://www.loopla.org/about/about.htm, accessed 10 September 2013.

Pal, P., Sikder, J., Roy, S., Giorno, L. (2009): Process intensification in lactic acid production: a review of membrane based processes, *Chemical Engineering and Processing*, **48**, pp.1549-1559.

Plastics Technology (2011): *Materials additives blends take PLA upscale*, available at http://www.ptonline.com/articles/materials-additives-blends-take-pla-upscale, accessed 10 November 2011.

Porter, M. E (1980): *Competitive Strategy: Techniques for Analyzing Industries and Competitors*, The Free Press, New York.

Plastics Today (2009): *Can PLA take next big step?*, available at http://www.plasticstoday.com/articles/can-pla-take-next-big-step, accessed 22 July 2012.

Purac (2012): *Presentations*, available at http://www.csmglobal.com/Corporate/Investor_Relations/Publications/Presentations.aspx, accessed 20 November 2012.

Rogers, E. M. (2003): *Diffusion of Innovations*, 5th ed, The Free Press, New York.

Sanders, J.P.M., Clark, J.H. , Harmsen G.J., Heeres, H.J., Heijnen, J.J., Kersten, S.R.A. , van Swaaij, W.P.M., Moulijn J.A. (2012): Process intensification in the future production of base chemicals from biomass, *Chemical Engineering and Processing*, **51**, pp.117-136.

Sanders, J.P.M., Langeveld J.W.A. (2010): *Introduction*, in: Langeveld J.W.A., Meeusen M., Sanders J. (ed.), The Biobased Economy: Biofuels, Materials and Chemicals in the post oil Era, Earthscan, Bristol, pp. 3-18.

Shen L, Haufe, J., Patel. M.K. (2009): *Product Overview and Market Projection of Emerging Biobased Plastics – PRO BIP 2009*, available at http://en.european-bioplastics.org/wp-content/uploads/2011/03/publications/PRO-BIP2009_Final_June_2009.pdf, accessed 20 June 2011.

Teece, D.J. (1986): Profiting from Technological Innovation: Implications for integration, collaboration, licensing and public policy, *Research Policy,* **15** (6), pp.285-305.

Wolf, O. (2005): *Techno-economic Feasibility of Large-scale Production of Bio-based Polymers in Europe*, available at http://ipts.jrc.ec.europa.eu/, accessed 11 December 2011.