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EXTERNALITIES AND THE SIX FACETS MODEL OF TECHNOLOGY MANAGEMENT: GENETICALLY MODIFIED ORGANISMS IN AGRIBUSINESS

STEPHEN R. LUXMORE* and CLYDE EIRÍKUR HULL†

Saunders College of Business, Rochester Institute of Technology
108 Lomb Memorial Drive, Rochester, New York 14623
United States of America
**sluxmore@saunders.rit.edu*
†chull@saunders.rit.edu

The Six Facets Model of technology management has previously only been applied to process innovation at the firm and the industry level. In this article, the model is applied to product innovation for the first time. In the context of genetically-modified organisms in the agribusiness industry, we examine radical product innovation through the Six Facets Model. We propose, based on the history of genetically-modified organisms in agribusiness, that when applied to product innovation the Six Facets Model will benefit considerably from the inclusion of potential negative externalities and the reactions of external stakeholders.

Keywords: Six Facets Model; negative externalities; product innovation; radical innovation; agribusiness; genetically-modified organisms.

1. Introduction

When a new technology is developed that solves an existing problem and costs less than the technology it might replace, what could keep it from being deployed successfully? To address this question we apply the Six Facets Model [Kearns *et al.* (2005)] to technological change at the industry level. Specifically, we examine the deployment of genetically-modified organisms (GMOs), a radical innovation in agribusiness. In so doing, we hope to provide insight into a problem that has bedeviled academics and researchers alike.

Kearns *et al.* [2005] suggest that the *process* by which a technology is deployed may break – or make – the technology's success, and propose six specific aspects of the process to manage for a successful deployment. The deployment process is important to the success of the deployed technology, but externalities play a huge role in the success of new technology, particularly when the technology is being deployed across a major industry rather than within a single company [Luxmore, 2005]. While Kearns *et al.* [2005] developed their Six Facets Model in the context of a technology being deployed within a company, Prakhya and Hull [2007] subsequently applied the model to the introduction of a radical new process technology in the printing industry. The model, then, can be applied broadly to new technology introduction at multiple units of analysis. When applied in the new context of the introduction of radical product innovation at the industry level, however, externalities must be explicitly recognized. Our application of the Six Facets Model to the radical innovation of GMOs in agribusiness thus serves both to address the question posed above and to strengthen the model.

The 1980s saw the first field trials of GMOs, and the technology has advanced rapidly since then [Biotechnology Industry Organization, Monsanto]. A multitude of GMOs are now available with very specific traits and resulting benefits to farmers and consumers. Despite this, GMOs face considerable resistance in the marketplace, to a large degree because of negative externalities [Hall and Martin (2005); Luxmore (2005); Luxmore and Shaw (2003)]. Negative externalities are by-products or side effects of a company's activities, which have negative consequences for entities not directly involved with those activities. Pollution and environmental degradation are classic examples of negative externalities, but any consequences of a company's activities that negatively impact outsiders qualify as negative externalities [Hall and Martin (2005)]. In the case of agribusiness and GMOs, many of the negative externalities associated with the resistance are externalities only in potential — they have been imagined, but have not (yet) happened in fact [Luxmore (2005)]. Arguably, the resistance associated with these potential negative externalities and, perhaps, some of the realized negative externalities associated with GMOs would have been mitigated or avoided if the technology had been deployed differently [Hull and Luxmore (2007)]. Though GMOs were introduced in a manner consistent with scientific rationality [Isaac and Kerr (2003); Luxmore (2005)], the companies introducing them suffered from a failure to adequately consider external stakeholders and negative externalities. Hall and Martin [2005] argue little attention has been given to innovation management outside of the traditional industry/market base approach and call for more research to address technology infused with societal issues. McWilliams and Siegel [2001] and Hull and Rothenberg [2008] provide broad-based evidence that successful innovators do take externalities into account, though the evidence is lacking in details as to how this is done. This examination of radical innovation and externalities through the lens of the Six Facets Model is meant to respond to Hall and Martin's [2005] call with a detailed discussion of the implementation of radical product innovation in the context of significant negative externalities.

How useful, then, is the Six Facets Model in the context of radical new high-technology products? Of new products in general with potential or realized negative externalities? We propose to apply the Six Facets Model to our opening question both in the model's original form and with externalities incorporated into each facet. Doing so will enhance our understanding of how to deploy radical innovations in general, and how to understand the difficulties facing GMOs in agribusiness more specifically. Doing so will also increase the value of the original Six Facets Model by broadening its applicability to include radical product innovation.

In Sec. 2 we briefly review the relevant literature and build on it to develop a theoretical proposition concerning externalities and the Six Facets Model. The case is then presented and is the foundation of the following section in which we conduct a Six Facets Model analysis of GMOs in agribusiness, with a sub-proposition for each facet. In our concluding section, we draw on the previous sections to develop practical insights, of potential interest to managers, that are based on our theoretical development and the analysis.

2. Literature Review and Theoretical Development

The Six Facets Model was originally developed by Kearns *et al.* [2005] to address how companies might achieve organizational fitness through needful innovation [McCarthy (2003)]. More specifically, it focused on process innovation, including the selection of new technology, but not, as Hull *et al.* [2007] note, the decision of whether to move to a new technology at all. The six facets are technology evaluation, product and process integration, planning, training, implementation, and change (see Fig. 1).

The first application of the Six Facets Model was to process innovation within one company. In 2006, Prakhya and Hull applied the model to a similar process innovation at the level of an industry rather than within a single firm. Though they demonstrated that the model applies at the industry level as well as at the firm level, they focused on an innovation with minimal externalities that had little or no impact on customers. In effect, the innovation, though radical, was a process innovation that had few side effects on outside parties. Radical product innovations with many potential negative externalities were outside the scope of their study.

In 2007, Hull *et al.* reexamined the Six Facets Model in the original context of process innovation within a firm based on new technology. One of their conclusions was that the model as it stands inadequately addresses the question raised by the protestors against GMOs: Is it time to abandon the old technology, or is it still more valuable than the new? The answer to this question is not always the same, and it is frequently not obvious. Hull *et al.* [2007] offer a modified analytic hierarchic process with which to address this question before proceeding to the six facets. In this study, our approach is different. We assume that a new technology is what Kim and Mauborgne [1997] call a value innovation — with lower costs and higher quality — or that if the new technology is more expensive and lower quality than the old that the new technology will be blocked by the Technology Evaluation facet.

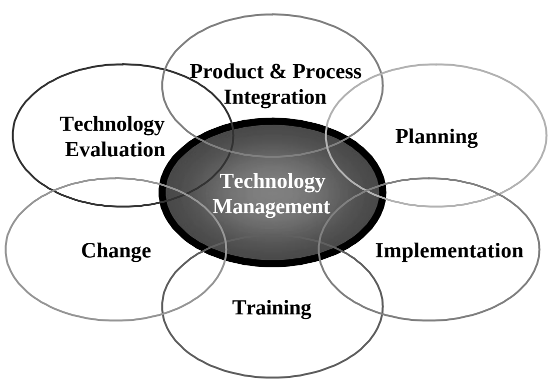

Fig. 1. The Six Facets of Technology Management. (*Source*: Kearns *et al.* [2005].)

	Process Innovation	Product Innovation
Firm-Level Innovation	Kearns *et al.* (2005) Hull *et al.* (2007)	
Industry-Level Innovation	Prakhya and Hull (2007)	Current Study

Fig. 2. Applications of the Six Facets Model.

Our focus is thus primarily on negative externalities. Rather than adding a new analysis to the model, we propose making adjustments to the existing facets to incorporate externalities.

Studies of the Six Facets Model have to date fallen into two of four possible categories, firm-level and industry-level process innovation (see Fig. 2). The current study, in addition to its other contributions, applies the model to a third category, product innovation at the industry level.

3. Case: Genetically-Modified Organisms and Agribusiness

3.1. *Methodology*

We use the agribusiness industry as our case study [Eisenhardt and Graebner (2007)] to refine the Six Facets Model. The case is relevant as there are a limited number of successful competitors in the GMO segment of the industry, despite significant investment by the early movers to be life science firms. Thus the selection of the industry as a single case study allows for contrast of prior and current industry behavior and success, which is well suited to our theory refinement [Eisenhardt and Graebner (2007)].

Our case data is drawn from secondary sources. Given both the relatively short duration of GMOs in agribusiness and the fascination of the business community, special interest groups and the public with our food chain, the industry, its evolution and major competitors is well documented.

3.2. *Genetically modified organisms in agribusiness*

Biotechnology has changed agriculture and food products for millennia. Between 4000 and 2000 B.C. biotechnology produced the fermentation of beer and wine, the production of cheese, the leavening of bread, and the selective pollination of date palm trees [Biotechnology Industry Organization (2008)]. The use of modern biotechnology such as GMOs in agribusiness is much more recent, beginning with field tests in the 1980s, commercialization in the 1990s, and rapidly accelerating application and product variation from then to the present.

Recombinant DNA (rDNA) techniques move DNA from one organism to another, yielding new and unique DNA strands that would otherwise not exist. These new DNA strands in turn yield GMOS. The potential benefits to mankind are enormous, but the belief that the benefits exceed the potential risks is not uniformly shared [Luxmore (2005); Luxmore and Shaw (2003)]. These externalities, whether real or potential is the focus of the present article. The risks associated with GMOs are well documented [Barnett and Gibson (1999); McHughen (2000); Nottingham (1998); Pringle (2003); Saigo (2000)] and include natural environment issues, human health concerns, and matters of economic, social and ethical dimensions.

The potential risks associated with GMOs limited the number of nations that first allowed GMO planting and harvesting, which has risen slowly to 23 nations in 2007. Yet six nations, the U.S., Argentina, Brazil, Canada, India and China, account for more than 90 percent of planted acres [Hindo (2007); James (2007)], and GMO crops still account for only about 7 percent of global agriculture acreage [Hindo (2007)]. GMOs and food derivatives are not universally accepted. The implication of this harsh market reality in most of the world [Darby and Zucker (2003)] has taken a toll on the industry. During the 1990s there was aggressive maneuvering in the biotechnology/life sciences industry including the agriculture segment. Today there are five major competitors in agribusiness: Monsanto, Bayer CropScience, Syngenta, Dow and Dupont. In the GMO segment, Monsanto is dominant [Hindo (2007)].

3.3. *Major competitors*

Monsanto began acquiring agriculture biotechnology firms in 1995 [Hoovers (2008b)] while divesting its chemical units, with the exception of agrochemicals [Hoovers (2008b)]. After Pharmacia and Upjohn and Monsanto merged in 2000, the new Monsanto division of Pharmacia further focused on GMO crops. However, public attacks on GMOs and Monsanto as a key player in GMO development contributed to the decision to partially spin off part of Monsanto in 2000, followed by a complete spin off in 2002 [Hoovers (2008b)]. Again, there was a 'new' Monsanto, which is the company that remains today. Currently Monsanto or Monsanto technology licensees account for more than 90 percent of all GMO seed sales [Hindo (2007)].

An early competitor to Monsanto, Aventis CropScience was born as a joint venture of the agribusiness divisions of Aventis and Schering AG [Hoovers (2008a)]. As had Pharmacia, these two pharmaceutical firms sought to separate their agribusiness activities from their other pursuits. But in 2001, just two years after it was formed, Aventis CropScience was taken over by Bayer [Hoovers (2008a); Luxmore and Shaw (2003)]. Today agrochemicals is Bayer CropScience's primary business activity [Hoovers (2008a)].

Syngenta AG was formed in 2000 in a similar manner as its competitors: its pharmaceutical parent organizations, Novartis and AstraZeneca, wanted to distance their agribusiness from their core business [Hoovers (2008c)]. As an independent agribusiness, Syngenta has not replicated the success of Monsanto in the area of GMOs. Syngenta's primary business activity is in agrochemicals, although recent investments and research efforts may increase its GMO activities [Hoovers (2008c)]. Hindo [2007] reports Syngenta earns less than 20 percent of its revenues from GMO seeds, and Dow Chemical has less than ten percent of its sales in this industry sector.

3.4. *Monsanto*

Within the biotechnology/GMO segment of agribusiness, Monsanto is now very profitable and has recently had significant innovation success with GMOs [Hindo (2007)]. But this was not always the case: "Having placed all its bets on biotech, Monsanto was stalled amid widespread controversy over its genetically altered soybeans and corn, derisively called "Frankenfoods" by critics abroad and at home" [LaGesse (2008)]. As noted above, Monsanto's success is centered in just six nations, with the addition of Brazil, China and India to the list of markets very recent. GMOs are now very successful in markets where negative externalities are perceived to be relatively small. In other potential markets, particularly Europe, where the externality issue is at the forefront, GMOs are not successful. While we can only speculate whether the industry could have been successful if stakeholder perspectives were integrated in the innovation process, we can state that including external elements in the innovation process could hardly have made the situation less tenable. Indeed, as discussed below, there is evidence that Monsanto has improved its market position since it began to include external market forces in its technology innovation process.

Monsanto established a cell biology research effort in 1975, followed this by forming a molecular biology group in 1981 and a genetically modified a plant cell in 1982, and began field trials of GMOs plants by 1987 [Monsanto (2008)]. In 1994 the first Monsanto biotechnology product approved and marketed was Posilac (bovine somatotropin (Bst)) a yield enhancing application for dairy cows [Monsanto (2008)]. This was followed by GMO soybean and cotton, introduced in 1996 [Monsanto (2008)]. Genetic modification was advancing rapidly at Monsanto.

Research efforts were directed by scientific capabilities from Monsanto's entering the GMO segment through 2002 [Hindo (2007)]. The result was excellent science applied to many agriculture products, including tomatoes, potatoes, bananas, rice, wheat, as well as the current success in soybean, corn and cotton [Hindo (2007, 2008)]. Today Monsanto focuses on the latter three crops [Hindo (2007, 2008)].

The success of GM corn, cotton and soybean in some markets and the lack of success of the other GM products in all markets seem to hinge on two factors. The three successful products are all targeted to industrial uses and enter the human food chain indirectly, if at all. The unsuccessful GM products, by contrast, are more likely to be consumed directly. The other factor is how externalities factor into the regulatory process for adoption on a national or regional level. In the USA the regulatory process follows scientific rationality principals, which may be contrasted with the EU where social rationality principals are applied. The result is only scientific evidence, not social factors such as externalities, is considered under the scientific rationality approach to regulation, whereas scientific and social aspects are examined under the social rationality approach. Additionally, interested parties such as NGOs opposed to GMOs may present their cases, without scientific proof, under the social rationality process.

Monsanto's executives began their GMO quest believing the market would accept the products of sound science and failed to consider the reactions of the public to GMOs [Watkins and Bazerman (2003)]. Hess and Hey [2001] elaborate on

Monsanto's belief that science would be the only consideration in the GMO market. Shortly after the merger to form Pharmacia, then CEO Verfaillie [2001] stated in reference to the Monsanto division "It got the science right ... [it] is solid, and it's world class" (p. 11). Nor did this occur without some consideration of stakeholders. Yet Hart and Sharma [2004] indicate that the stakeholder group was too tightly bound and did not extend to those at the fringe, who would become the vocal objectors to GMOs. Verfaille [2001] included in his speech that more stakeholders would be considered in future decision-making.

Hindo [2007] indicates that not until 2003, after the complete spin off of the company and the appointment of new CEO Grant, did Monsanto include all stakeholders in its research and product development. This directional shift coincides with the refocus of genetic modification research and product development on agribusiness and industrial markets, and a deliberate move away from end use consumer products such as vegetable and fruits through genetic engineering. Monsanto employee Cockburn [2004], Director of Scientific Affairs, Europe and Africa, identified three generations of biotechnology products in agribusiness. The first generation involves traits to develop crops that are herbicide tolerant, target specific insect attack, or are stacked with genes to do both. He stated that most new crops would continue with similar technology applications [Cockburn (2004)]. The second generation products would focus on nutritional enhancement. This area is continuing under the Grant era at Monsanto, but with an emphasis on agriculture application such as animal feed and a de-emphasized on direct human consumption in response to public opinion [Hindo (2007, 2008)]. The third generation products were defined as industrial application such as renewable feedstock for packaging material or fuel.

Monsanto is also attempting to leverage its biotechnology expertise to transform its vegetable seed business, but without the use of GM technology. From its base genomic research the firm is applying its discoveries to enhance seed variety [Cockburn (2004); Grant (2008)]. This technological approach may also be applied to the primary field crops. Recently Monsanto divested the Posilac (bovine growth hormone, rBST, supplement) business, which was under attack from public interest groups [Anonymous (2008)].

4. Proposition Development

At the firm level, the process of adopting technology, specifically GMOs, has been very successful. Monsanto markets GMOs and dominates the market in the primary GMO growing nations of the US, Argentina, Brazil, and Canada and markets that are using more GMOs, such as India and China [Hindo (2007)]. But Monsanto's relative success with GMOs was hard fought and hard won. Innovations such as recombinant DNA create metamorphic change in an industry and the ability of firms to succeed in under these conditions is difficult "due to the extensive tacit knowledge required to practice them [new technology] and the lengthy period of learning-by-doing-with at the lab bench required to transfer them" [Darby and Zucker (2003, p. 2)]. For biotechnology industries "The knowledge base and skill-set requirement to innovate require a very sophisticated understanding of science and technology" [Mohan-Neill and Scholle (2008, p. 69)]. Monsanto's successful internal technology adoption and application is consistent with the Six Facets Model. But as we demonstrate below, its success coincides with the recent (since 2002) consideration of external stakeholders [Hindo (2007)], which is consistent with our adjusted Six Facets Model.

Thus our approach is to examine whether the Six Facets Model can explain the relative sales success in nations such as the US, in nations with very low GMO sales and, of course, in the majority of the world, with zero use of GMOs. We will demonstrate that the application of the original Six Facets Model is appropriate for innovations without significant effect outside the firm, but is not sufficient when the technological change results in significant externalities. Our finding is consistent with Kearns *et al.* [2005] and Prakhya and Hull [2007]: when negative externalities are non-existent or a non-factor such as the case of the US, Argentina, Brazil, Canada and similar adapting nations, the internal application of the six facets is sufficient. However, when new products create potential or real externalities, such factors need to be considered in adopt/don't adopt decision processes, and the six facets need to be applied to external stakeholders as well.

4.1. *Adjusted six facets model*

We begin the development of the adjusted six facets model with an overarching proposition:

Proposition 1. *The original Six Facets Model is necessary to successfully implement internal technology, but not sufficient when external stakeholders may reject the technology or resulting product. In such cases, the model must address negative externalities.*

We validate Proposition 1 by dissecting the six facets model one facet at a time. Each facet analysis begins with a sub-proposition derived from the overarching proposition, and the validity of each is demonstrated.

4.1.1. *Technology evaluation*

Proposition 1A. *The original technology evaluation facet is necessary to successfully implement internal technology, but not sufficient when external stakeholder positions may reject the technology or resulting product. In such cases, technology evaluation must include an evaluation of potential negative externalities.*

Beginning with technology evaluation, we see in radical product innovation a significant difference from earlier applications. In prior applications the emphasis has been on process: the success of implementing technological change within the firm. The process application is well developed and substantiated for the printing industry (see Prakhya and Hull [2007]) and the Body Shop (see Kearns *et al.* [2005]). As opposed to previous applications of the Six Facet Model, in the present study *commercialization* of new technology is critical.

In the case of GMOs the success of Monsanto in many markets attests to Monsanto's successful internal technological change, and is consistent with prior studies. However, Monsanto's inability to replicate its success across all agricultural markets indicates the presence of other factors. GMOs, like other radical innovations, are products that have associated benefits and costs, but external stakeholders disagree with Monsanto over the relative magnitude of the benefits and costs. Thus, technological change in the case of radical innovation should include external stakeholder considerations [Luxmore (2005); Luxmore and Shaw (2003)].

Not only does this technological change affect the firm value chain, it also affects the industry value chain. Consistent with prior studies we believe technology selection is important, but in the case of GMOs, technology selection also must include external stakeholders, from those who buy the seeds all the way to the consumers – and beyond [Hall and Martin (2005); Luxmore (2005); Luxmore and Shaw (2003)]. Many stakeholders value GMOs and buy them, while other stakeholders reject the technology. Understanding the range of stakeholder reactions and examining and evaluating potential ways to mitigate the negative ones in advance is crucial to technology evaluation for radical product innovations.

Including external stakeholders in a technology evaluation of GMOs would show Monsanto or other firms in similar circumstances that the proposed technology change might be rejected. This might imply that another technology could be more desirable, or the intended application of the technology might need to be altered. In our specific study this might mean developing new GMO hybrids that deliver value to more stakeholders and minimize negative externalities, or implementing technological change with full knowledge of the external constraints. A less ambitious introduction of GMOs might have wasted less effort and met with less resistance — saving money in the short term and possibly increasing total market share in the long term.

Monsanto's early failure to focus its development efforts on products that deliver value to more stakeholders and minimize negative externalities stems from its incomplete technology evaluation, which excluded external perspectives. The emphasis was on technological excellence, with less consideration of commercialization. For example Monsanto expended significant resources to develop products, such as golden rice, that would deliver improved nutritional value, but these efforts have now been reduced. LaGesse [2008] says of Monsanto's earlier years in GMOs, "The company was ... seen as a corporate bully, trying to ram the new technology down the throats of farmers."

In 2002 Monsanto sought approval of roundup ready (herbicide tolerant) wheat in the US, Canada and Japan. In the important growing markets of Canada and the US the new variety was subject to government approval, but the US regulatory policy is much less stringent than that in Canada. All new wheat varieties in Canada are subject to licensing approval under the Canada Seeds Act [Berwald *et al.*, 2006]. Since Monsanto was treating the Canada and US market as a single market, the wheat for North America was not commercialized because the Canadian government refused a license for the new variety.

Market concerns forced Monsanto to withdraw the wheat GMO. Export market perceptions of GM products coupled with US wheat producers exporting more than 50 percent of their crop was a key consideration [Martin, 2004]. Social movement organizations (NGOs) joined with farmer groups to successfully oppose the

GM wheat [Magnan (2007)]. Syngenta is working on a GM-wheat which will be fusarium-resistant [Berwald *et al.* (2006)], but the company is looking beyond 2010 as an introduction date as it continues to interact with stakeholders to assess the acceptance of the product [Heller (2006)]. So, it appears that the industry participants are learning to consider external stakeholders and negative externalities as a critical part of technology evaluation.

Monsanto has more recently concentrated on products that minimize negative externalities and have the best possibility for commercialization: crops that deliver benefits to the farmer, are destined for animal feed, are widely accepted across the world [Hindo (2007)] and with industrial applications such as textiles and biofuel [Hindo (2008)]. He reports Monsanto implemented this product evaluation system after 2002. While Monsanto has addressed 'stakeholder' positions in its literature since the 1990s, the transformation of the company's research focus as described by Hindo [2007] is significant. The firm focused on the crops it was currently marketing successfully: corn, soybean, cotton and canola. Future R&D efforts were to concentrate on new and stacked (multiple existing desirable traits from different varieties) traits for these crops. According to Hindo [2007, pp. 36–37], "Grant [Monsanto CEO] also made a crucial strategic decision to pare down the products Monsanto sold. No longer would Monsanto sell seeds for produce destined directly for the dinner plate. Instead Grant focused exclusively on seeds for agribusiness, ones that produced such goods as animal feed, ethanol, and corn syrup." At Monsanto, technology evaluation is now clearly focusing on external consideration of commercialization.

The application of the original technology evaluation facet within the firm is necessary as demonstrated by Kearns *et al.* [2005], but is not sufficient in cases characterized by significant externalities which inhibit rapid commercialization of new technological products such as GMOs. In these cases, negative externalities must be considered.

4.1.2. *Product and process integration*

Proposition 1B. *The original product and process facet is necessary to successfully implement internal technology, but not sufficient when external stakeholder positions may reject the technology or resulting product. In such cases, product and process integration may cause both product and process to be rejected, when otherwise only one would have been rejected. Before they are integrated, the reactions to negative externalities of all external stakeholders at every stage of the industry value chain should be considered.*

This facet, product and process integration has referred to integration and interaction within the organization [Kearns *et al.* (2005)]. In the context of product innovation, it refers to integration and interaction throughout the industry value chain. The industry process from purveyor of technologically induced GMOs to farmer, to mill, to food processor, to grocery chain and restaurants, to end use consumer is critical to product acceptance across all markets. Again, commercialization considerations indicate the integration process must include all stakeholders to the industry value chain.

While the integration of GMOs products is the norm in the United States and other GMO accepting nations, GMO shunning nations and regions have halted the integration at various points along the industry value chain. Various stakeholders opposed to GMOs have stopped the integration at the farm level by refusing to purchase crops, and in some instances vandalizing fields. Mills that process GMOs have been removed from potential supplier lists by food processors, even if they separate GMO from non-GMO processing, as non-contamination cannot be assured. The withdrawal by Monsanto of its GMO wheat is due in part to perceptions in export markets [Martin (2004)]. Some grocery chains and restaurants will not buy from food processors that use GMO inputs, and consumers have the choice not to purchase GMOs in some nations and regions, and have no access in other nations. Hindo [2007, p. 37] notes "In August, Kroger (KR) became the latest US grocery chain to stop selling milk with a GMO bovine growth hormone that increases production, which Monsanto first started selling in 1994. All summer, activists in France trampled fields of biotech crops. Hostility toward GMO foods continues to be widespread in Africa and parts of Asia and Western Europe." More recently Kraft announced that it will produce rBST free cheese [Sterrett (2008)]. Kraft follows in the footsteps of companies that ban or restrict rBST milk and related products such as Dean Foods, Starbucks and Kroger [Sterrett (2008)]. Integrating product and process normally makes sense, but if either product or process carries significant negative externalities, it may contaminate the other when they are integrated.

The application of this facet, as originally conceived, to the organization is necessary as demonstrated by Kearns *et al.* [2005], but is not sufficient in cases characterized by significant externalities which inhibit rapid commercialization of new technological products such as GMOs. In such cases, negative externalities may indicate that a delay, potentially indefinite, of product and process integration is necessary.

4.1.3. *Planning*

Proposition 1C. *The original planning facet is necessary to successfully implement internal technology, but not sufficient when external stakeholder positions may reject the technology or resulting product. In such cases, planning must incorporate solutions to potential negative externalities and include external stakeholders.*

As originally developed, the planning facet emphasized allocating the right resources and personnel to successful implementation of technological change. Kearns *et al.* [2005] and Prakhya and Hull [2007] demonstrate this for Body Works and the printing industry respectively. Certainly this holds for GMOs as well for internal matters.

But GMOs are being rejected or constrained in many markets. We believe an external stakeholder viewpoint must be incorporated along two dimensions. First, all managers and employees must have the skill and training to be able to measure and assess stakeholder perspectives. These attitudes and expectations need to be delineated and understood by the organization. Hindo [2007, p. 38] relates the absence of this aspect at Monsanto: "Grant's decision caught many of Monsanto's scientists off guard: Several research programs aimed at producing things people eat were axed over the course of the year, among them biotech wheat, an extra-durable tomato, blight-resistant potatoes, and bananas bred with an innate defense against virus." R&D at Monsanto was determined internally, without considering whether people would buy these products.

Second, external stakeholders need to be a component of the planning process. Stakeholder perspectives toward new technology, which differ substantially from the expectations of the developing or adopting firms, are critical to successful technology implementation. End users and those who face potential negative externalities should be considered and planned for to avoid misallocating assets [Prakhya and Hull, 2007]. Certainly in the case of GMOs Monsanto would have been well advised to initially minimize resource allocation to nations and regions that were restricting or banning GMOs, which could have been identified and assessed prior to implementation as a component of the planning process. Alternatively Monsanto could have allocated its resources differently based upon national and regional differences in attitudes to GMOs. For example in North America the resources would have been used to influence farmers, while in the EU the initial resource allocation could have been toward public relations and policies.

As Kearns *et al.* [2005] illustrate, planning is necessary for successful internal technology implementation. But it is not sufficient (unless externalities are considered) in cases similar to GMOs in which substantive externalities act to restrict or completely impede technology adaptation. Monsanto is changing its planning approach internally and externally [Hindo (2007)].

4.1.4. *Implementation*

Proposition 1D. *The original implementation facet is necessary to successfully implement internal technology, but not sufficient when external stakeholder positions may reject the technology or resulting product. In such cases, implementation is likely to encounter negative externalities and external stakeholders' reactions to those externalities.*

Kearns *et al.* [2005] and Prakhya and Hull [2007] stress the human factor in the technology implementation process. Training people to use the technology is important to internal technology success. In the introduction of radically innovative technological products the same logic may be applied to external stakeholders.

Monsanto should have been prepared to educate the users of GMOs: farmers, mills, food processors, grocery stores, and end use consumers. Successful change and training is critical internally [Prakhya and Hull (2007)] and externally. In the case of GMOs, there is a significant level of misinformation and resulting negative attitudes to be prevalent [Isaac and Kerr (2003)]. Education may reduce the probability and/or degree of negativity to GMOs.

The original implementation facet is necessary for successful internal technology implementation [Kearns *et al.* (2005)]. It is not sufficient in cases, such as GMOs, in which substantive externalities act to restrict or completely impede technology adaptation. External stakeholders must be continually involved in the process. In the case of Monsanto, "Where the company had once protected its internal research papers like state secrets, it began publishing some of them in refereed scientific journals" [Hindo (2008, p. 39)]. And this is coupled with a more conciliatory stance to the market.

While Monsanto enjoys significant market advantage over its nearest competitors Syngenta, Dow and DuPont, it is still being assertive in next-generation GM products. BASF and Monsanto are collaborating in the development of stacked-gene GM canola, corn, cotton and soybeans that resist drought and heat [Mitchell (2007)]. This alliance accomplishes two things for Monsanto: it brings an EU-based firm to Monsanto's camp, and) it gives Monsanto access to technological expertise it does not possess [Mitchell (2007)]. Of these two factors, the former is likely to be more important. BASF's success in the EU indicates that it is better able than Monsanto to incorporate external stakeholders into their implementation. Learning how to do so from BASF could be the best advantage this alliance yields Monsanto.

4.1.5. *Training*

Proposition 1E. *The original training facet is necessary to successfully implement internal technology, but not sufficient when external stakeholder positions may reject the technology or resulting product. In such cases, training must include raising employee awareness of external stakeholders and potential negative externalities.*

Prakhya and Hull [2007, p. 7] state, "When PDF was introduced, it encountered considerable skepticism in the printing industry, but it has now evolved into the fundamental file structure." The same parallel is evolving with GMOs.

Research at Monsanto is expanding beyond 'round-up ready' varieties of crop, and researchers are evidently aware of external stakeholder concerns with actual and potential negative externalities. Seeds are being marketed that could benefit farmers and end-use consumers. This is a result of all six facets internally and in the context of external stakeholders, but is particularly well-illustrated under the training facet. Researchers are answering market demands for products that benefit developing nation farmers and consumers. "As the debate quiets down, demand for genetically modified crops has exploded. The economic emergence of China and India has lifted income levels for billions, who, like their wealthier middle-class counterparts in the West, are now eating meat several times a day. That has driven a surge in demand for animal feed" [Hindo (2007, pp. 40–41)]. And Monsanto has entered these markets to help farmers to meet the needs. In 2007 China and India planted 10 million hectares of many different GM crops: this is more than the plantings in Canada, in all of Europe, in all of Africa, and in the rest of the Asia-Pacific region [James (2007)].

While training with respect to the technology in question is necessary to the success of technological implementation [Kearns *et al.* (2005)], it is not sufficient. In cases, such as GMOs, where substantive externalities act to restrict or completely impede technology adaptation, employees should be trained to include external stakeholders and their objections to developing technology and marketing new products. This training should include employees who have no customer or market contact as well as those who do [Vargo and Lusch (2004)].

4.1.6. *Change*

Proposition 1F. *The original change facet is necessary to successfully implement internal technology, but not sufficient when external stakeholder positions may reject the technology or resulting product. In such cases, change must incorporate solutions to negative externalities.*

As have the companies examined in Kearns *et al.* [2005] and Prakhya and Hull [2007] Monsanto has adopted change internally. It has also adopted the change mentality necessary to respond to market forces. As stated above, the technology is being applied to new GMO products developed to benefit consumers and minimize negative external stakeholder perceptions and/or reduce the likelihood of successful campaigns against GMOs. If it hadn't responded to external stakeholder pressures, Monsanto probably would not have expanded beyond the initial GMO-friendly markets.

Kearns *et al.* [2005] establish that internal change is necessary to the success of technological implementation. However, it is not sufficient when substantive externalities exist. In order to foster technology development that generates marketable product, companies must consider external stakeholder constraints. There is some evidence to support this occurring in the industry as an academic researcher relates her experience of interacting with industry at conferences which has gone from hostility in the 1990s to today where "Monsanto and other companies in the industry are much more respectful and interested in what we are doing." [Hindo (2008, p. 41)]. Clearly the industry is responding to external opposition and is slowly changing to include other scientific evidence as well as opinions in the technology management process.

5. Continuing Issues

Agro-biotechnology companies are adjusting their development and marketing processes to recognize external market forces as outlined above. But they continue to find opposition to GMOs and still have difficulty negotiating controversial scenarios. In particular, they seem to have trouble accepting that the detractors of GMOs may have legitimate concerns.

Mittal [2008] makes a horrific claim that GM cotton is contributing to the increase of poverty and even suicide among farmers in India: The higher cost of GM seed, the greater use of insecticides, lower yields and higher susceptibility to a specific disease have reduced farm incomes and increased debt. As a consequence farmers, and in some instances their families, are committing suicide in unprecedented numbers.

The agri-industry association CropLife withdrew from the International Assessment of Agriculture Science and Technology (IAAST) over disagreement of the draft report of the IAAST that addresses agriculture policies to reduce world hunger.

The IAAST is a coalition of academics, NGOs, industry, government, the UN, and farmers groups. CropLife removed itself from the coalition due to the coalition's exclusion of biotechnology as a critical element of alleviating world hunger, questioning the evidence that GM crops have higher yields, and its discussion of the risks of biotechnology to developing nations [Nature (2008)]. This is clearly a missed opportunity for CropLife and the agribusiness industry as a whole, which should have welcomed the discussion. It might have learned a great deal about real and perceived negative externalities, and it might have been able to teach the other side something about the usefulness of GMOs as well. And this is not the only report to take the position that biotechnology is not part of the mainstream solution to world hunger. While CropLife states they support the goals of the IAAST, their withdrawal indicates that firms like Monsanto and Syngenta still have room to improve the integration of external stakeholders in their technology management processes.

The efforts of the industry to protect intellectual property rights remains an area of contention; one that opponents of GM crops are quick to use in their anti-GMO campaigns. Activist groups argue terminator technology (also called suicide seeds: seeds which will be sterile in the second generation so farmers cannot save them to plant) is an affront to the rights of farmers, particularly in developing nations, and Monsanto's use of this technique is immoral [Bustos (2007)]. While protection of intellectual property is essential, stakeholder perceptions should be included in the management decision.

Activists are not surrendering on the introduction of new GM crops or GM crops to new areas. Greenpeace hailed Romania's decision to ban GE corn (GE maize MON 810, the only GM crop allowed in the EU) (US Federal News Service, 2008). And activists of the Sierra Club, Center for Food Safety, High Mowing Organic Seeds and the Organic Seed Alliance are suing to halt the commercial planting of GM sugar beets in the United States [Melcer (2008)].

There has been found a Bt-resistant bollworm in the US [Biotechnology News, 2008)]. Should this become more widespread this will need to be addressed by the industry as Bt corn and cotton are widely sold. Anti-GM forces will be quick to use such a scenario in their campaigns.

In short, though Monsanto and the other GMO-producing companies have made progress, there is no shortage of negative externalities for them to face. The application of the Six Facets Model, as modified by the inclusion of externalities and external stakeholders, may benefit to them, and other companies trying to introduce other radical product innovations.

6. Conclusion

We have expanded the application of the Six Facets Model from process innovation at the firm [Kearns *et al.* (2005)] and industry level [Prakhya and Hull (2007)] by focusing on the applicability of the model to product innovation. In applying the model to GMOs in agribusiness, we deliberately chose a radical product innovation, as this is the sort most likely to generate negative externalities. Considerable negative externalities have impacted GMO product innovation, and will likely continue to do so. It appears that our proposition and its sub-propositions are supported by the available evidence in the case of GMOs. Though this is a single industry example, the principles at work do seem to apply to other industries as well [c.f., Hull and Luxmore (2007)]. One contribution of this article is thus the expansion of the Six Facets Model to include product as well as process innovation, with the concomitant requirement that externalities be seriously considered within all six facets when it is applied to product innovation (see Fig. 3).

However, our assumption that evaluating externalities is not necessary for process innovation remains an assumption. A reasonable case could be made that it is, in fact, necessary no matter what the innovation. We suggest that a future study could evaluate negative externalities in a Six Facets Model process innovation application. Here, we have simply shown that it appears necessary when product innovation, particularly radical product innovation, is to be attempted. Further empirical study is called for, preferably using data from a different source, perhaps within a different industry facing a different radical product innovation.

The practical applications of this study are twofold. One is that the Six Facets Model can be applied to the introduction of product as well as process innovations. The other is that negative externalities will cause negative 'internalities' — companies with radical product innovations that do not go out of their way to identify and neutralize negative externalities will find themselves under siege rather than welcomed by customers. If even companies as large and successful as Monsanto are forced to learn this lesson from experience, it appears to be a lesson that every company seeking to renew itself through new product introduction should heed.

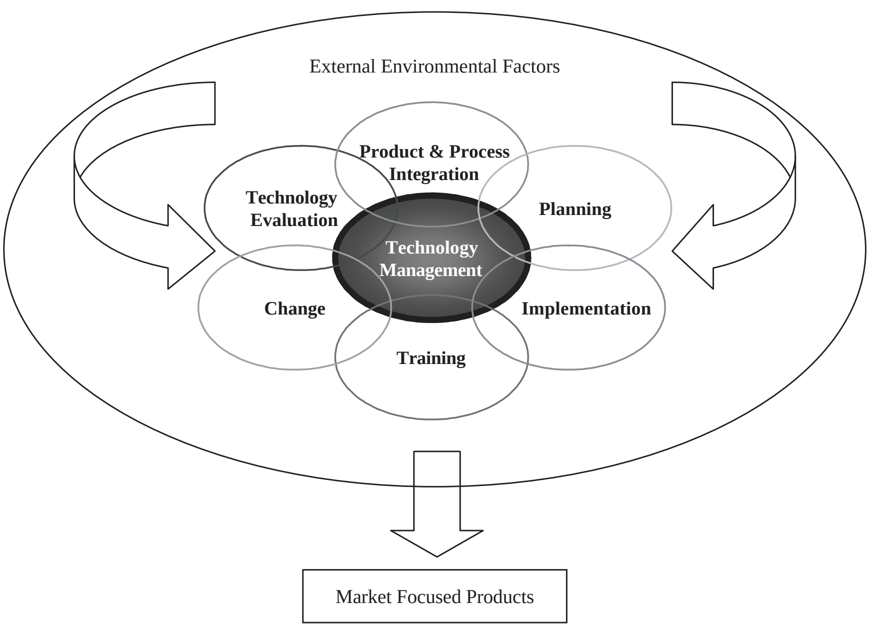

Fig. 3. The revised Six Facets Model of Technology Management.

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Biography

Stephen R. Luxmore is an Assistant Professor of International Business in the E. Philip Saunders College of Business at Rochester Institute of Technology. His research interests include international strategy, innovation and technology and agribusiness. His Ph.D. is from the University of Toronto.

Clyde Eiríkur Hull is an Associate Professor in the E. Philip Saunders College of Business at Rochester Institute of Technology, where he is also a Zutes Faculty Fellow and Program Director of the MS in Innovation Management degree. He earned his Ph.D. from the Indiana University Kelley School of Business. He has been a high-tech entrepreneur, and he began consulting in technology and strategy in the 1990's. His research interests include innovation and technology strategy, entrepreneurship, corporate social responsibility, and business and corporate strategy.