

**INNOVATION IN THE FOOD  
AND AGRICULTURAL INDUSTRIES:  
A COMPLEX ADAPTIVE SYSTEM**

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## **Abstract**

Innovation is critical to the long-term success of a firm as well as the economic health of an industry and the overall economy. This manuscript presents an overview of the management literature regarding technology and innovation management. It also describes the unique characteristics of the food and agricultural sector and offers a research agenda to extend the management literature to the agribusiness sector.

Key Words: Innovation, agribusiness, portfolio of options, risk

JEL Code: L24, D81, O31, O32

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# INNOVATION IN THE FOOD AND AGRICULTURAL INDUSTRIES: A COMPLEX ADAPTIVE SYSTEM

## **Introduction**

Innovation is critical to the long-term success of a firm as well as the economic health of an industry and the overall economy (Gertner, 2004). Many authors have written about the importance of innovation. Brown and Teisberg (2003; p1) stated that “Innovation is the lifeblood of successful businesses. [...] [It] has become every firm’s imperative as the pace of change accelerates. The challenges of this imperative increasingly require leaders to manage uncertainty and pursue learning and innovation across the boundaries of firms”. Successful companies, like Google, devote a significant share of their time to innovation (Iyer and Davenport, 2008). The Boston Consulting Group (2006) surveyed executives in their 2005 innovation survey. The group found that 90% of the surveyed executives believe organic growth through innovation is essential and nearly three-quarters of these executives will increase spending on innovation (The Boston Consulting Group, 2006). McKinsey surveyed top executives and found that more than 70% consider that innovation will be at least one of the top three drivers of growth for their company in the next three to five years (Barsh et al., 2008).

The agribusiness sector is no stranger to this phenomenon. Even though in terms of R&D spending as a percentage of sales the food and agricultural industries is not perceived as a high tech<sup>1</sup> industry, there has been significant amount of innovative activity in terms of food products as well as agricultural production inputs. Over the last 150 years, there have been several waves of innovation related to machinery, chemistry, seed, information management (Graff et al., 2003; Gray et al., 2004).

Innovation is important from the perspective of the individual firm, the industry/sector, and the overall economy/society. From the perspective of the firm, innovation in new products/services is one strategy to develop and maintain a sustainable competitive advantage. New product/service introductions are also one approach to growth which is important in many industries, particularly those financed by the public sector capital markets. Process innovation combined with implementing new management system innovations contributes to cost reductions, quality enhancement and process improvement which are critical to a firm’s long term financial success, particularly for those who are participating in commodity industries. From an industry or sector perspective, product and process innovations are particularly important to productivity improvements, which some argue is the lynch-pin of improved economic performance in an industry as well as in the overall economy. The total factor productivity of the U.S. agricultural production sector has significantly increased since the late 1940s thanks to innovation in machinery and plant and animal production technology. Certainly differences in productivity growth driven by innovation and resource availability are critical to the global competitiveness of the agricultural sectors in various countries as evidenced by

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<sup>1</sup> The term “high tech” seems to be a buzzword without a clear definition. However, this paper follows the definition of Shanklin/Ryans (1984), p. 166, who define three criteria which a business must meet in order to qualify for being “high-tech”. These encompass: (1) a strong scientific-technical basis, (2) fast technological change which may make existing technologies obsolete, and (3) new technologies get developed whose applications create or revolutionize markets and demand. See also Carroll et al. (2000), p. 420 f., who classify technology by using criteria such as R&D-intensity, rate of technological innovation, and technological endowment of the end final products in an industry

Brazil's rapid development and growing dominance of not only soybean production, but also poultry, pork, and beef production in the world.

Finally, innovation is essential to respond to the critical concerns of society such as climate change and global warming, food/energy scarcity and security, environmental challenges or resource use/sustainability. Many of these innovations will be in the form of products/services or processes that improve the effectiveness and efficiency of responding to these social/economic challenges (e.g., dealing with the measurement and mitigation of negative externalities.) Others will be institutional innovations such as new markets for carbon sequestering or a cap and trade system to reduce greenhouse gas emissions, or new management systems such as lifecycle analysis to respond to resource constraints, environmental problems and sustainability issues. Some of these innovations will be in the form of creative public/private sector ventures such as the agreement between Novartis and the University of California for basic research in agricultural genomics (Klotz-Ingram and Day-Rubenstein, 1999.) Hence, innovations in the food and agricultural industries can be induced by different triggers and are occurring across the entire food supply chain with different implications for innovating firms and the entire food and agricultural industries.

Given the need for innovation for firms in the agricultural and food industries to grow, the question is whether or not existing research on technology and innovation management can be applied to this industry, or if there may be industry characteristics that call for a more industry-specific approach to innovation management. In order to further elaborate on this question, this paper first identifies the unique characteristics of the food and agricultural sector. Then a concise overview of the most relevant technology and innovation management (TIM) literature is provided. This leads us to answering the question of how well current theoretical frameworks of the TIM-literature can be applied to the food and agricultural industries, thus resulting in a future research agenda for TIM-research in the food and agricultural industries.

### **Food and Agriculture: A Complex Adaptive Industry**

Even though the agrifood sector is not regarded as high-tech, each year there are many innovations being commercialized. For instance from a Business to Customer (B2C)-perspective, 859 new food and drink products are introduced into the U.S. market annually as defined by new packaging, sizes and functionality features (Toops, 2009). Historically, a high percentage (75%) of these new food product introductions have not been successful introductions as evidenced by sales less than \$7.5 million (Toops, 2009.) On the Business to Business (B2B) level, in the agricultural input supply industries, new product introductions in the form of biotechnology and information technology have dramatically expanded the new product service offerings from the traditional machinery and equipment, fertilizer, seed and chemical industries.

As illustrated in Table 1, the food and agricultural industry is characterized by a number of features which challenge and shape the innovation process: volatility, long production cycles, slow growth, complex supply chains, traceability/food safety, highly regulated, technological convergence, a commodity industry and consolidation/coordination of a very fragmented industry. These characteristics can be classified into two major categories-- complexity and adaptiveness.

**Table 1. Characteristics of the food and agricultural industries**

<b>Complexity</b>	<b>Adaptiveness</b>
<b>a) Long production cycles</b>	a) Volatility in: <ul style="list-style-type: none"> <li>- Price</li> <li>- Product quality</li> <li>- Production conditions</li> </ul>
<b>b) Slow growth markets</b>	b) Industry convergence
<b>c) Complexity in supply chains</b>	c) Commodity nature of raw materials
<b>d) High degree of regulation</b>	d) Industry consolidation
<b>e) Traceability and food safety requirements</b>	e) Increasing need for chain coordination
<b>f) Quality standards</b>	

### **Complexity**

Particularly at the raw material stages of the value chain, fundamental characteristics of the biological production process influence the rate of progress and speed of innovative activity. In general, agricultural production is characterized by *long production cycles* and batch production processes, which mean that in general the time delays between a new idea and a commercially viable product, are much longer than in industries characterized by continuous flow processing and short production cycles. Biological growth experiments generally have longer life cycles than engineering or mechanical technology innovations. Even with the use of gene marker technology that significantly accelerates the process of identifying a desirable crop production trait that has commercial potential, it still takes between 8 and 10 years to move that trait once identified into a plant variety that can be commercially sold in the market. This difference in the duration between new idea and commercialization influences the innovation strategy in the food and agricultural industry compared to those industries with shorter duration times.

An additional important characteristic of the food and agricultural industries is its mature market which is characterized by limited/slow growth in demand. A *slow growth market* fundamentally challenges new innovations because, in essence new products must cannibalize the market share –since this one is not growing- and market position of current products to successfully enter the marketplace. Thus, the market acceptance hurdle for innovations in this industry is higher than for other industries that have a more rapidly growing market space where new products or innovations can enter without having to push aside or capture market share from current, well established products or innovations.

The food and agribusiness industry is also characterized by very *complex supply chains* that are not well coordinated, particularly among the up-stream stages in that chain. For example, the supply chain providing inputs to the production sector (fertilizer, seed, chemicals, machinery) is relatively well coordinated, particularly in terms of logistics, information flow and aligned governance systems. In contrast, the linkage between input suppliers and producers/farmers, as well as the linkage between producers/farmers and product purchasers is not necessarily well coordinated in terms of the information flows, logistics, etc. Part of the problem is that the production sector in general is very fragmented which provides challenges for those firms further downstream that desire traceability or guaranteed quality attributes. As will be discussed later,

innovations that require adoption/adjustment across the entire value chain (e.g. systemic innovations) are much more difficult to adopt and implement if that value chain is not only complex, but also fragmented and not well coordinated.

The food and agribusiness industry, particularly at the stages of direct consumption by animals and humans, is a **highly regulated industry**. Not unlike the health and pharmaceutical industry, regulatory compliance requires not just financial commitments, but equally if not more important can result in significant time delays as well as uncertainty in the approval process and therefore product commercialization. The prospect of regulatory delays and the risk of regulatory approval clearly influence the willingness to make upfront commitments to innovations that face not just technological and market acceptance uncertainty, but may also encounter regulatory/compliance uncertainties. Such uncertainty may also shape the governance structures and use of various business models such as joint ventures, strategic alliances and licensing agreements to develop and commercialize an innovation.

**Traceability, and food safety requirements, and quality standards** are increasingly being implemented to respond to concerns about animal health and food safety. Improved risk management processes and forecasting procedures are additional examples of process innovation that firms are adopting and implementing to respond to the increased volatility in agricultural production and prices. Process improvement resulting from new technology and management practices resulting from advances in engineering and computational processing technology are common place in the agricultural production, processing and distribution industries.

### **Adaptiveness**

The food and agricultural industry is very dynamic. This is reflected by its high **volatility**, both in production and market conditions. A combination of biological production processes that are subjected to unpredictable disease and pest infestations combined with variable climatic/weather/heat/rainfall patterns and conditions results in significant fluctuations in growing/production conditions and thus efficiency and output. This fluctuation in output or supply combined with the inelastic or non-responsive demand for food products results in dramatic price fluctuations, particularly at the raw materials level in the supply chain. High volatility and consequently the limited ability to predict the future results in higher risk of the future payoff of today's investment in innovation projects. Hence, the industry itself is not only dynamic, but it also demands a high degree of dynamic capabilities of firms to adjust the the volatility.

Technological convergence plays an important role for the food and agricultural sector, as it may lead to a blurring of industry boundaries. This phenomenon is also referred to as **industry convergence** and can be observed by the application of different technologies across different industries which may result in new "inter-industry segments" (Bröring et al., 2006). With respect to agribusiness, convergence can be seen in the use of biotechnology and genetic engineering to alter the disease, insect and weed resistance of plants, thus redefining the boundaries of the seed and chemical industries and transferring a significant portion of the value previously generated by the herbicide and pesticide industries to the seed/genetics industries.

The *commodity nature of the raw material* stages of the food and agribusiness value chain presents unique challenges and opportunities. On the one hand, firms that are successful in commodity industries generally focus on operational efficiency and low cost strategies, thus restricting the opportunity for R&D and other expenditures for new product innovations. Furthermore, successful innovations in a commodity industry are difficult to identify and commercialize since customers in most cases are not used to paying for unique differentiating features. At the same time, a break-through innovation in a commodity industry has the potential to redefine that commodity; so although the likelihood of identifying such an innovation is very low, the payoff of a successful break-through innovation that redefines the commodity is very high since it gives the successful firm a leading position in that industry.

Finally, the food and agricultural industries, particularly in the production and input sectors, has traditionally been dominated by small scale, independent firms. But changes are occurring rapidly – firms are both **consolidating** and becoming more tightly **coordinated** along the value chain. Business model innovation has increased in recent times with the adoption of various forms of contract production systems particularly in livestock production, joint ventures and strategic alliances between various seed and chemical companies, and licensing agreements specifically in the biotechnology based industries. This consolidation/coordination process also facilitates innovation by a firm or industry in the form of entire management systems including total quality management, scenario analysis, enterprise risk management, balanced scorecarding, continuous process improvement, and product lifecycle management. Thus, innovation can be of various forms and is increasingly pervasive in the dynamically changing agricultural sector.

These unique characteristics of the food and agriculture industries combined with the fact that innovation by definition suggests change, challenges the static equilibrium assumptions of traditional economic theory. Instead, the analytical framework to assess innovation must be dynamic in both time and uncertainty dimensions rather than static. Innovation is complex and characterized by nonlinear processes, open rather than closed systems, incomplete rather than perfect costless information, and errors/biases in decisions. And innovation should be viewed as adaptive in that it results in constant adjustment/change, learning from successes and failures, and thus evolutionary processes. In summary, one should view innovation in the food and agricultural industry as a complex adaptive process that requires a broader and more powerful analytical framework than that offered by the traditional equilibrium driven theory of the firm economic concepts (Beinhocker, 2006).

### **Review of the General Technology and Innovation Management Literature**

The literature on technology and innovation management combines a plethora of different streams of themes, frameworks and specific models. From a fundamental theory point of view, this paper follows the resource-based view (RBV) of strategy, firm behavior and decision-making. From a resource-based perspective, innovations are new combinations of existing and/or new resources and competencies (Penrose 1959, p. 85). Hauschildt argues that such a “new combination” must at least advance to the stage of market introduction as a new product, or must be utilized as a new process in production (Hauschildt 2004, p. 25). Since R&D endeavors can also be exploited in other terms (e.g. licensing), any new combination of existing and/or new resources and competencies which is commercially exploited is an innovation (Roberts 1988, p.

11). Hence, commercialization is a critical delineator between an invention and an innovation, and is essential to its definition. Therefore, in this discussion, we define innovation as a product, a service, a process, a new business model, or a management system that solves a problem.

Futhermore, innovation is contingent on particular factors and contexts. The context of this paper is the food and agricultural sectors, which we propose may be characterized by sector-specificities potentially calling for an industry-specific approach to innovation. Hence, the environmental dynamics affecting technology and innovation management are an important exogenous factor in addition to internal factors such as the organizations resources and competencies.<sup>2</sup> Therefore, the contingency approach complements the resource-based view, as it proposes that organizational performance is a result of a proper alignment of endogenous design variables with exogenous context variables.<sup>3</sup> This paper follows Aragon-Correa and Sharma (2003) who integrate the resource-based view and the contingency approach.<sup>4</sup> The goal is to understand the influence of specific industry characteristics for innovation managment.

Due to the vast majority of different studies, we use the following logic to review the existing literature. We start with a brief review of the work on drivers of innovation and then move to an overview of the different ways innovation has been characterized and distinguished. We then show how the innovation process is structured and organized, and finally provide a summary of the literature regarding innovation portfolio management and risk management.

### **Drivers for Innovation**

A very basic question of innovaton management is where does innovation come from and why are firm's engaging in innovation. Hence, much work has been devoted on the driver for innovation. One fundamental approach of distunguishing a driver for innovation can be seen in the degree to which an innovation originates from new technologies, "technology push", or wether it has been derived from a market need, "market pull". As Mowery and Rosenberg (1979) assert, the presumed importance of market pull over technology push is not justified by empirical evidence: "*Rather than viewing either the existence of a market demand or the existence of a technological opportunity as each representing a sufficient condition for an innovation to occur, one should consider them each as necessary, ..., both must exist simultaneously.*" Although both market demand and technological opportunity should ideally be present, R&D projects differ on which of these two drivers is dominating. While some projects are rather technology-driven (e.g. triggered by new technologies such as biotechnology) others may be more market driven (e.g. convenience products in fast moving consumer goods markets) (Hauser, 1988).

Another driver can be seen in new regulations which abandon or allow certain production factors for innovations (for example new ingredients) and thereby create a new market.

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<sup>2</sup> As Poole/Van de Ven (2000), p. 650, argue "internal-external relations between the innovation unit and its environment are very important in understanding the innovation process."

<sup>3</sup> Compare the contributions of Burns/Stalker (1961); Lawrence/Lorsch (1967).

<sup>4</sup> Aragon-Correa/Sharma (2003), p. 73.

## **Forms/Types of Innovation**

Innovation can be of many forms or types as illustrated in Table 2. An important moderating variable which has drawn much attention in the TIM-literature is the *degree of innovativeness*. Hence, different levels of innovativeness have to be distinguished. These range from “new to the world” products to incremental “repositioning” (Crawford and di Benedetto, 2003; Song and Montoya-Weiss, 1998). By extending the degree of innovativeness Christensen et al. (2004) segmented innovations into sustaining and disruptive innovations (Some use the terminology incremental and radical innovations (e.g., Leifer et al., 2000), or continuous and discontinuous innovations (e.g., Dewar and Dutton, 1986).) Sustaining/ incremental/ continuous innovations consist of improving a current product using existing knowledge and to mainly serve existing markets. Disruptive/ radical/ discontinuous innovation refers to the creation of a new product or value proposition.

Henderson and Clark (1990) further define innovation using a typology focused on *technology types* which distinguish between the component of a product and the way the components are integrated into the product. Their typology classifies innovation into incremental (or component), modular, architectural, and radical innovations. Incremental innovations refer to relatively minor changes to the existing product’s components and no changes in the design, linkages, or interfaces between the components. Innovations that significantly change the components but do not change the linkages are called modular innovation. Architectural innovations leave the core design concepts untouched, but change the way in which the components of a product are linked together. In contrast, radical innovations change both the core design concepts and the linkages.

Hauser (2008) looks at the *scope (and impact) of an innovation* and identifies three types: operational efficiencies/operations/process innovation, new products/new services innovation, and business model innovation. Operations innovation consists of improving the effectiveness and efficiency of core functional areas such as data processing, manufacturing, accounting, human resources etc. New products/new services innovation refers to innovation at the product or service level. Business model innovations include consideration such as organizational structure changes, strategic partnerships, franchising, licensing, shared services, divestitures, or a new way of servicing the customers.

Furthermore, innovations can be distinguished according to the degree of *involvement they require from the entire value chain*. In other words, innovations can be segmented as systemic or autonomous. Systemic innovations do not stand alone but require different partners in the supply chain to adapt in order to make them work (Chesbrough and Teece, 1996; Teece, 2000; Taylor, 2005). Autonomous innovations, as their name indicates, require only one partner in the supply chain to make changes for the innovation to be successful.

According to Eto (1991), innovations can be classified by their *source of funding*. This factor is related to the risks involved, with corporate funded projects generally involving higher risks than business unit funded R&D projects. Indeed, corporate R&D projects, of mostly large multinationals, focus on future technologies/radical innovation which are riskier, while business units focus on incremental innovation.

The innovation can also vary in terms the *degree of knowledge building* (Reus et al., 2009). Innovations in basic research versus applied research can be distinguished (Hauser, 1998; Meade

and Presley, 2002.) Innovations at the basic research level focus on creating or updating a technology. Innovations in applied research focus more on the development or improvement on a product.

The question of “*firm boundaries*” of innovations (either “open” or “closed”) are topical and has received much recent attention, since firms have realized to open up their innovation processes particularly when the innovation is extremely radical and the competence gaps are important (Chesbrough, 2003). Chesbrough (2003) promoted the term and the concept of open innovation versus closed innovation. In the past, companies have had a mentality of closed innovation, i.e., generating and producing their own ideas. Lately, we have seen more and more companies embracing open innovations because of increasing global competition and rising research and development (R&D) costs (OECD, 2008). Firms now more frequently use external ideas and partners (suppliers, competitors, customers, universities) to bring an idea to market faster than the competition (OECD, 2008). Open innovation has faced and is still facing some difficulties. For open innovation to be successful, all involved parties need to win something from the collaboration. This requires the write-up of complete contracts that are always hard to write ((Besanko et al., 2000)<sup>5</sup>.

Among these different approaches to distinguish and identify certain R&D projects, the literature discusses innovations occurring as a result of *industry convergence*. Industry convergence can be defined as a ‘blurring’ of boundaries between industries (Bröring et al., 2006). In the context of converging industries, companies can either exploit existing competences, thereby continue to follow their existing path of development. Or they may break with the existing path and create new capacity through partners in this “new” industry. This results in two different types of R&D projects in converging industries: path-dependent innovation and path-breaking innovation. Path-dependent innovation does not face any resource misfits and, thus, operates only in the familiar area/industry. Path-breaking innovation faces a lack of absorptive capacity, defined as the ability for sense-making about external development, due to the fact of really entering a new “industry” with new characteristics (Bröring, et al. 2006).

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<sup>5</sup> Firms seek open innovation to share capabilities (financial, technological, human, etc) and the risk involved in investment of specific assets. Holdup problems arise when firms invest in specific assets required for a specific transaction. Assets can be called specific when, for example, a specific location needs to be chosen. Specificity can also come in the form of physical or engineering properties that are specific to a relationship. Dedicated assets are also specific in the sense that an investment in an asset is made to satisfy a particular party. Finally, specificity can also take a human form in the sense that employees may have acquired skills, or know-how that are more valuable for a particular relationship/transaction than for others. The difference between the profits a firm will make by deploying the specific assets in their intended use and the profits the firm would make in the best alternate use of the specific assets is called quasi-rents. Trading partners can hold up parties that have quasi-rents by trying to transfer the quasi-rent to their firm. This is called the holdup problem and is particularly likely when contracts are incomplete. Because of the holdup problem, contract negotiations can be extremely lengthy and parties can underinvest in relationship-specific assets (Besanko et al., 2000).

Table 2. Different Types of innovation

Dimension	Dichotomy	Study
Innovativeness	Radical vs. Incremental Sustaining vs. Disruptive Discontinuous vs. Continuous	Christensen et al. (2004) Dewar and Dutton (1986) Song and Montoya-Weiss (1998) Crawford and di Benedetto (2003) Veryzer (1998) Schmidt and Calantone (1998)
Technology	Incremental (or component) vs. Modular vs. Architectural vs. Radical	Henderson and Clark (1990)
Scope of innovation	Operational Efficiencies/ Operations/ Process vs. Product/ Services vs. Business Model	Killen et al., 2008 Hauser (2008)
Autonomy of Innovation	Autonomous vs. Systemic	Chesbrough and Teece (1996) Teece (2000)
Source of Funding	Corporate vs. Business Unit	Eto (1991)
Degree of Knowledge Building	Basic Research vs. Applied Research	Hauser (1998) Meade and Presley (2002)
Firm Boundaries	Open vs. Closed	Chesbrough (2003)
Industry Boundaries and Company Evolution	Stable vs. Converging Path depending vs. Path breaking	Stiglietz (2004) Bröring et al. (2006)

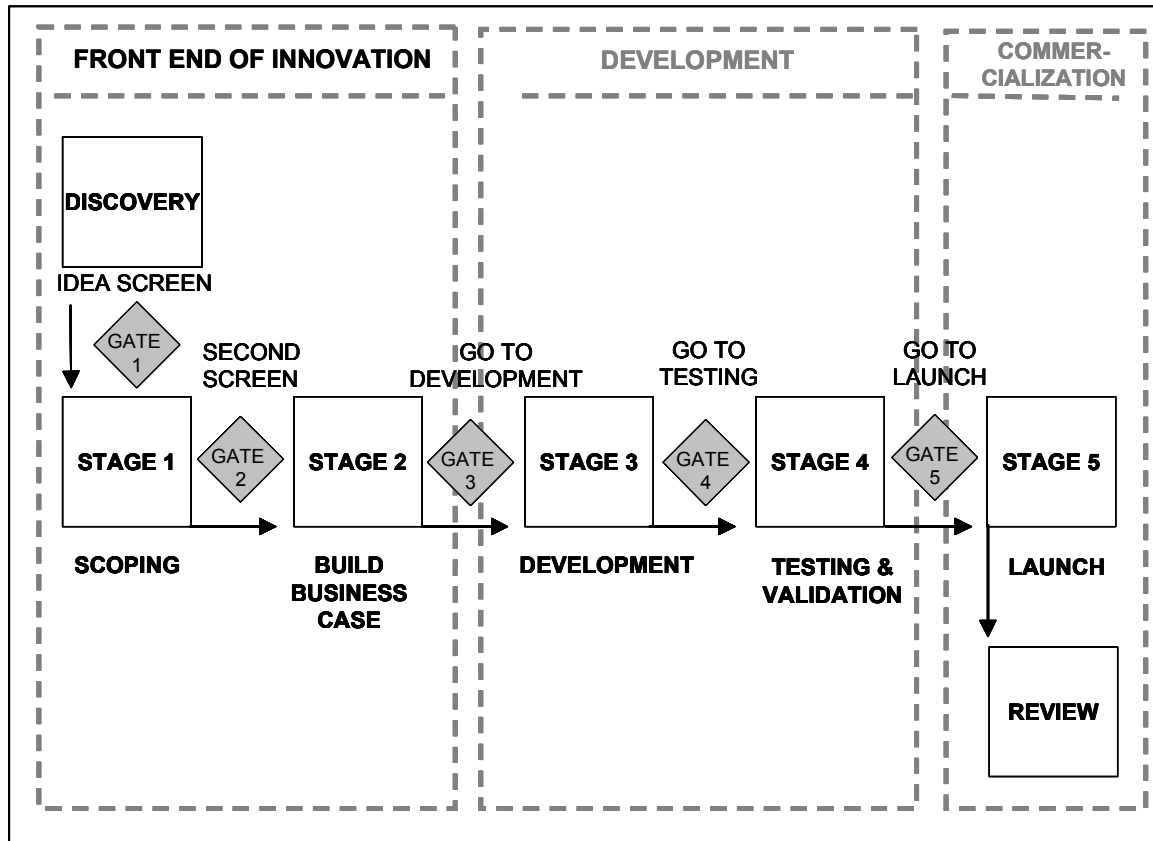
**Source: adapted from Bröring (2005).**

### **Organizing innovation**

Numerous studies have analyzed the various stages of innovation and introduction of new products/services into the market. A common classification or categorization (see e.g. Cohen and Levinthal, 1989) of these stages in the management literature is exploration/invention (which captures the activities of transforming an idea or insight into a specific product/service offering and illustrates the degree of learning and competence building), and exploitation or commercialization (which involves the activities of moving that new product/service through the stage gate process to assess its value in the market place and actually offer it to customers or end users). The innovation process itself has been described by various authors resulting in a high

number of different approaches.<sup>6</sup> Probably the most wide-spread used conceptualization of the innovation process is Cooper's stage-gate process (Cooper, 2001; p130; see Figure 1)<sup>7</sup>.

**Figure 1. Cooper's Stage-gate Process as an Example for Innovation Process Models**



Source: Bröring (2005) adapted from Cooper (2001), p 130.

Prior to the stage-gate process, comes the discovery stage which consists of creating a culture and a set of activities to discover opportunities and generate new innovation ideas (Roth and Sneider, 2006; Brown, 2005; Barsh et al., 2008). As shown in Figure 1, Cooper's stage gate process consists of five stages of different activities (scoping, build business case, development, testing and validation, launch) and five gates where the output of these activities is assessed/reviewed. As suggested by Broring (2005) and Koen et al. (2002, p.6), Cooper's stage gate process can be split into three main phases: front end of innovation or Fuzzy Front End, development, and commercialization.

Scoping (stage 1) consists of a quick and inexpensive evaluation of the technical merits of the project and its market prospects. If the results of stage 1 are satisfactory, the project moves to stage 2 where a business case is built. Cooper (2001) argues that this is the critical stage that

<sup>6</sup> For a broad overview on studies related to new product development see Brown/Eisenhardt (1995).

<sup>7</sup> The stage-gate system has initially been introduced by Cooper in 1990 as a "new tool for managing new products", compare Cooper (1990), p. 44. Note: for those who do not have access to the book, the Product Development Institute, Inc's web site has great information regarding Cooper's stage gate process at <http://www.prod-dev.com/stage-gate.php>

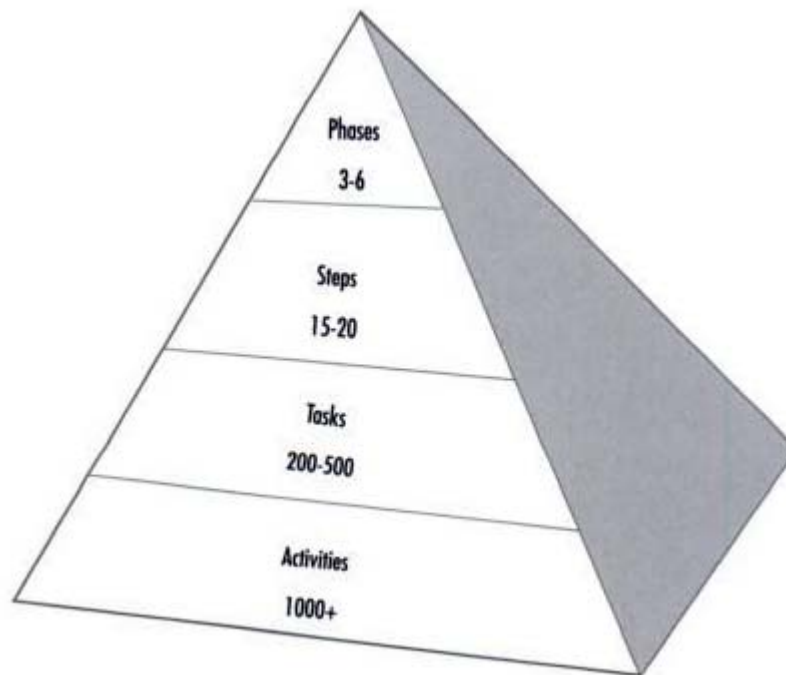
usually determines whether the project will successfully pass through the stage-gate process or whether it will be killed. At this stage, technical, market and business feasibility analyses are performed. This results in the writing of a business case. Stage 3 is where the product is developed and designed. The manufacturing or operations plan, the marketing launch and operating plans, and the test plans for the next stage are mapped out. At stage 4, the plans/assumptions are tested and validated at the production/manufacturing, product design, market, and financial levels. Stage 5 is the final stage. This is the beginning of full production and the full commercialization of the project.

The gates are used to make decisions based on the presentation of the results of the analysis realized at the corresponding stage. The decision is two folds: 1) Go/kill decision and 2) prioritization decision. The go/kill decision consists of identifying which projects should not continue to be pursued and which projects have a good potential for success and should continue to receive resources. Prioritization decisions consist of allocating the resources to the different projects. Another three phase model of the innovation process using the same logic as Cooper (2001) can be found in Gerpott (1999). He describes the three phases from an idea perspective: (1) Idea Generation and Selection, (2) Idea Realisation and (3) Idea Commercialisation.

Similar to Gerpott (1999) Mohanty et al. (2005, p5205) summarize these six activities into three phases: 1) basic phase, 2) applied phase, and 3) development phase. The basic phase is the stage during which the knowledge concerning the technology and the needed resources is collected through methods such as surveys, various laboratory studies, process plans of previous products, economic evaluations of different process plans. In the applied phase, the technology is developed and process plans for the development of the new products are mapped out. Feasibility studies and economic evaluations are also conducted in this phase. During the development phase, the technology developed in the previous phase is used to develop the new product. Design, quality, and procurement issues are considered at this time. The activities described in Mohanty et al's three phases are similar to Cooper's. However, the stages are a lot less cross-functional than Cooper's.

According to McGrath and Aklyama (1996) a number of companies also use the "PACE<sup>®</sup> approach" (see Figure 2) for managing product development. Structural development under PACE consists of four hierarchical levels. These include phases, steps, tasks and activities. Compared to the general stage gate process it adds two more layers which include tasks and activities in the steps (stages of the stage gate).

**Figure 2. The PACE® Approach**



Source: McGrath and Akiyama(1996)

Having a stage-gate process allows for an accelerated speed to market as the stages are cross functional and involve several activities (research and development, technical, market, financial, operations, etc). It increases the likelihood of success as projects are evaluated at each gate (and often within gate) at set periods of time. It introduces discipline into an ordinarily chaotic process that is filled with uncertainty. It allows for a formal process to review the resource allocation and possibly change the prioritization of projects. This formal process is also important to manage risk through incremental investments and increasing commitments: as uncertainties decrease and the innovation appears to have a larger probability of success, expenditures are allowed to rise. If the uncertainties increase and the probability of success decreases, the project may be killed. Alternatively, if the uncertainties and probabilities of success stay constant, the project may be stopped momentarily. In addition, by following a formal process, companies make sure that no critical step is omitted.

Koen et al. (2002) warns that “The Stage Gate™ process is an effective tool for accelerating incremental product development. However, it cannot be directly used for the front end of innovation since the front end has a highly interactive and complex character which cannot be crammed into the linear sequential structure of the stage gate. This holds especially true for platform projects or breakthrough innovations. Platform products need to begin with a strategic vision which will lead to a family of products based on an in-depth understanding of the market and how the companies core competencies and capabilities may be used to build competitive advantage.” The stage gate process does not preclude the assessment of any type of innovation. What may matter within the gate is the list of criteria that are taken into account. Hence, the

context and type of innovation project is an important contingency for any design of a innovation process.

In addition to the gating decision process, companies have portfolio reviews. In other words, projects are reviewed individually to move from one gate to another and portfolio decisions are also made periodically (monthly, quarterly, semi-annually, annually) on all projects together. This often creates conflicts particularly when different people are involved in the two types of reviews. Therefore, it is important to make sure both processes individually work well and are also harmonized (Cooper et al., 1997).

### **Portfolio Selection and Risk Management**

Developing profitable new innovations is critical to firm success (Chao and Kavadias, 2008). In addition, selecting the right portfolio of innovations is also important (Cooper et al., 1998). Innovation project portfolio management (PPM) (Killen et al., 2008) has at least two objectives: 1) selecting the right number of projects, 2) selecting projects that are diversified. A firm that takes on too many projects will strain its financial and human resources (Wheelwright and Clark, 1992). The presence of too many projects will also cause delays, loss of productivity, and quality issues (Wheelwright and Clark, 1992). Wheelwright and Clark (1992) also mention that too many projects will not allow the resources to be focused on the most significant innovations.

We summarize the research on methods to select the right innovations and the right set of innovations (i.e., the right portfolio) at each gate of the innovation process as well as the criteria considered in these decisions.

### **The Selection Methods**

Research and development (R&D) project selection is a complicated and challenging task to The selection of innovation projects is a complicated and challenging task to organizations for at least three reasons: (1) innovation has a significant impact on a firm's current and future financial position, (2) R&D funds are a precious but limited resource, which makes their effective use of utmost importance, and (3) the future success of innovation projects is hard to predict accurately (Bard et al., 1988; Hall and Nauda, 1988; Tian et al., 2005; Heidenberger and Stummer, 1999; Cooper et al., 1999). In the past four decades, several R&D project selection methods have been proposed (e.g., Heidenberger and Stummer, 1999; Hall and Nauda, 1988; DePiante Henriksen and Traynor, 1999) to help organizations make better decisions in R&D project selection. Table 3 summarizes the methods. DePiante Henriksen and Traynor (1999) and Hall and Nauda (1988) provide a more comprehensive definition of those methods and a more extensive list of studies in the R&D project selection literature.

The selection methods range from extremely simple to extremely complex/mathematically elaborate. As the size of firm increases, decision-makers are more likely to use more complex selection methods in addition or as replacement of the more primitive ones, although the mathematical methods in general have not really been broadly adopted (Cooper et al., 1998; DePiante Henriksen and Traynor, 1999). Each of the selection methods presented has advantages and drawbacks (as suggested by the list in the Table 3 that is not exhaustive) and none of them can meet all the company's goals. To deal with the limits of each method and have a more

informed decision-making approach, top performing companies are using a combination of those methods (Cooper et al., 1998; Coldrick et al., 2005) to serve the different goals (Cooper et al., 1997). Economic models and scorecarding are used to make sure the value of the portfolio is maximized. Mapping selection methods are utilized to have a visual model and make sure the portfolio is balanced. Decision models are useful to check the strategic fit of each project and allocate resources.

**Table 3. Categories of R&D Project Selection Methods**

Category of R&D Project Selection Method	Definition	Examples of Types	Examples of Studies	Advantages	Disadvantages
Ad-hoc methods	<p>Opportunistic: Take on projects as the opportunities arise</p> <p>Gut feeling: choose projects that sound successful</p> <p>Scientists driven/Genius award: let successful researchers choose their innovation projects</p> <p>Unstructured peer review: Two or more referees (such as expert, peer) comment on the same innovation project</p>		<p>Johnston (1988)</p> <p>Whitney (2007)</p>	<p>Easy to use</p> <p>May be adapted for small companies who are just starting to innovate</p> <p>Useful when frameworks are not in place or when the situation is too complex to be modeled</p>	<p>May not allow for a lot of radical innovation</p> <p>No formal process to make sure the portfolio is diversified</p> <p>Successful researchers, peers are not always successful strategists</p> <p>Subjective</p>
Mapping/ Graphical illustration	<p>Organize the projects on a matrix/map/figure based on a few dimensions (types of customers, type of projects, type of innovation, uncertainty, market share, market growth, platforms,...)</p>	<p>BCG Growth-Share Matrix</p> <p>Strategic buckets</p> <p>McKinsey matrix</p> <p>R&amp;D Project Portfolio Matrix</p> <p>McGrath-MacMillan Framework</p> <p>Bubble diagrams</p> <p>Decision trees</p>	<p>Wheelwright and Clark (1992)</p> <p>Chao and Kavadias (2008)</p> <p>Day (1977)</p> <p>Cooper et al. (1997),</p> <p>Cooper et al. (2001)</p> <p>Hsuan Mikkola (2001)</p> <p>Hax and Majluf (1983)</p>	<p>Allow decision-makers to think about a diversified portfolio</p> <p>Easy to use and understand</p>	<p>The graphical illustration by nature limits the number of dimensions that can be analyzed at once.</p>

		Game theory	McGrath and MacMillan (2000)		
Structured assessment	Widely used. Decision makers score each project on a series of criteria that are each given a weight. Projects are then compared based on their weighted score.	Structure peer review Checklist Scorecarding Multiattribute utility theory (MAUT) Analytic network process (ANP)/ Analytical Hierarchy Process (AHP) Delphi Q-sort	DePiante Henriksen and Traynor (1999) Thurston (1990) Hess (1993) Meade and Presley (2002) Zahedi (1986) Ringuest and Graves (1989)	Can include both qualitative and quantitative data (Coldrick et al. 2005) Simple to use (Hall and Nauda, 1988) Very useful with complex problems (Heidenberger and Stummer, 1999)	May become very time consuming (Heidenberger and Stummer, 1999)
Economic models	These models attempt to calculate some sort of financial value of a project	Economic indexes Internal rate of return (IRR) Net present value (NPV) Return on investment (ROI) Cost-benefit analysis Discounted cash flow Option pricing theory Simulation models and computer based decision support	Silverman (1981) Hess (1985) Faulkner (1996) Luehrman (1997)	Less subject to bias than qualitative data Facilitates comparison among R&D projects and with alternative investment projects (Heidenberger and Stummer, 1999) Risk may be embedded in those models with simulation modeling (e.g.,	Hard to translate some qualitative criteria/variables into numerical values (Heidenberger and Stummer, 1999) IRR favors projects that have shorter payback times so it should only be used to compare projects that have similar timescales (Coldrick et al. 2005) NPV favors large scale

		system (DSS)		Martino, 1995 and Milling, 1996)	projects (Coldrick et al. 2005) Treat each project in isolation (Farrukh et al., 2000)
Complex models	Mathematical Programming (integer programming; linear programming; non linear programming; goal programming, dynamic programming, fuzzy programming): select the projects that will optimize some objective function(s) (e.g., utility, market share, profit, risk) subject to a set of constraints (e.g., resources, time). Heuristic modeling: lead to acceptable but not always optimal solutions (Heidenberger and Stummer, 1999) Cognitive modeling/ Artificial intelligence (statistical approaches, regression models, expert systems, decision process analysis): model previous decisions to automatically make decisions regarding a new project that has comparable circumstances		Ringuest and Graves (1989) Blanning (1981) Schmidt (1993) Soyibo (1985) Graves et al. (2000) Venkatraman and Venkatraman (1995) Coffin and Taylor (1996) Martino (1995) Cooper (1981)	Time saving (less meetings)	So mathematically elaborate that they necessitate the assistance of mathematicians, expert decision analysts (DePiante Henriksen and Traynor, 1999; Heidenberger and Stummer, 1999) Hard to communicate Hard to translate some qualitative criteria/variables into a number Some necessary data are hard to obtain or are not collected (Heidenberger and Stummer, 1999) Simplifications are necessary

### The Criteria

At the essence of all the selection methods is a set of criteria; some selection methods include more criteria than others. Table 4 identifies the criteria that have been proposed when selecting innovation projects. We use Mohanty et al. (2005)'s classification. The drivers/criteria can be categorized as project attributes, organizational attributes, market attributes, and environmental attributes. Some relate to strategic questions (e.g., relevance, capability) while others are more

financial (e.g., return, time to market). Including these criteria in the selection methods used by companies, will allow decision-makers to have a disciplined process to screen innovations throughout the innovation process to review assumptions, gaps in information, expose problems that may or may not be fixed and detect potential sources of risk (Day, 2007). As the uncertainty is resolved and as the project moves along the stages of the innovation cycle (Sporleder et al., 2008), the criterion typically become less qualitative and more quantitative. Companies focus primarily on financial criteria such as net present value, internal rate of return, return on investment, etc. (Meade and Presley, 2002). However, top innovators appear to be using qualitative criteria in addition to the traditional financial criteria (Cooper et al., 1998).

**Table 4. List of Criteria to Take into Account when Selecting Innovation Projects**

<b>Criterion</b>	<b>Definition</b>	<b>Studies</b>
<i>Project Attributes</i>		
Resources/ Costs and Reasonableness	Level of resources (raw materials, initial outlays, employees, ...) needed to allow for the success of the project Are the suggested resources allocated to the project sufficient to allow a successful completion from a time and budget standpoint?	DePiante Henriksen and Traynor (1999), Ringuest and Graves (1989)
Time to market/ Time performance	The project's length of time from ideation to product launch	Hsuan Mikkola (2001), Farrukh et al. (2000), Cooper et al. (1998)
Risk	Scientific/ technical, market uncertainty; probability of failure or success	DePiante Henriksen and Traynor (1999), Bard et al. (1988), Hess (1993), Ringuest et al. (1999), Day (2007), McGrath and MacMillan (2000)
<i>Organizational Attributes</i>		
Relevance	Degree to which the proposed project supports the organization's mission and strategic objectives	DePiante Henriksen and Traynor (1999), Day (2007)
Capability/ Competitive advantage	Company's capability to produce and market the product compared to competitors	Steele (1988), Day (2007)
Qualitative return	1) the impact of the project on basic or fundamental research, 2) the impact of the project on programmatic or applied research,	DePiante Henriksen and Traynor (1999)
Internal competition	Will the project cannibalize firm's current offerings?	Bard et al. (1988)

<i>Market Attributes</i>		
Product demand	Is there a market, is it big enough? Are there complementary products or raw inputs that could increase the product's success?	Day (2007), Hess (1993), Ringuest and Graves (1989), Bard et al. (1988)
Competition/ Market share	What will be the number of competitors? How aggressive will they be? How successful will their product be?	Day (2007), Hess (1993), Ringuest and Graves (1989), Bard et al. (1988)
<i>Environmental Attributes</i>		
IPR/ Protectability	Ability to achieve sustainable competitive advantage via patents or proprietary knowledge	Cooper et al. (1998)

Organizational structures can also be used as a way to mitigate risk. Indeed, McGrath and MacMillan (2000) integrate the concept of real options, i.e., the concept that an innovation decision can be implemented in a step-by-step approach as uncertainty unfolds, creating an added value (Boehlje et al., 2005; Brown and Olmsted Teisberg, 2003). McGrath and MacMillan (2000) propose, as an application of real option theory (i.e., as a way to mitigate risk), the collaboration of firms through various governance structures with different commitment levels (e.g., from spot market to merger and acquisition). As uncertainties evolve, the choice of governance structure may also change.

### **Research Agenda**

The area of technology and innovation management is well established within management research; however, when it comes to its application to the food and agricultural industries, there has been less work done so far. We here identify some of the key questions that merit analysis concerning the drivers of innovation, types of innovation, organisation of innovation, and portfolio and risk management in the food and agricultural industries.

### **Drivers/Determinants/Outcomes of Innovation**

Most of the research (e.g., Sunding and Zilberman, 2000; Huffman and Evenson, 1993; Pardey and Beintema, 2001) on innovation in the agricultural sector in the past has emphasized the issues of technology adoption, productivity increases, and induced innovation. This work has focused primarily on the results and impacts of innovation and less on the drivers/determinants of innovation. The work has been more sector than industry or firm level focused. Additional research focused on drivers and outcomes might answer the following questions:

- 1) What are the industry and business climate characteristics that explain innovation, and what is the relative importance of these characteristics?
- 2) What are the firm characteristics associated with the exploration stage and the exploitation stage of innovation, and what is the relative importance of these characteristics?

- 3) What are the implications of innovation on financial performance? On sustainable competitive advantage?
- 4) What intra-firm processes are most effective in facilitating the exploration and exploitation stages of innovation?
- 5) What are suitable scenario and foresight activities for the food and agri-industries to identify future drivers for innovation?

As to industry and business climate characteristics, both the exploration and exploitation activities of the innovation process are hypothesized to be impacted by the level of concentration and rivalry in the industry, the science base of the industry and the speed of scientific advancement, the existence of substitute products/technologies, the amount of tacit versus explicit knowledge required to produce the product/service, the expectations of the customer base with respect to continuous innovation and new products, and the requirements for complementary products/services of suppliers and other supply chain partners in the distribution channel to deliver the innovative products/service. The specific contingencies of the agricultural sector need to be taken into account, e.g. approval of genetic modified foods; labeling and traceability issues as well as different influences from the consumer base. It is also important to recognize influences from related industries, which may result in industry convergence with the agricultural sector (Bröring, 2005). Furthermore, government policy with respect to protection of intellectual property rights and patent and contract law also are expected to influence the level and rate of both exploration and exploitation.

Characteristics of the firm are also expected to impact the innovation process; such characteristics as profitability, market share, R&D expenditures as a percent of sales, industry leadership position, core competences, networks, access to public research institutes, governance structure as well as brand status and brand value merit analysis. Finally, intra-firm processes and procedures that are hypothesized to impact innovation include diversity of skill sets of employees, strategies to stimulate creativity of employees, use of a stage gate evaluation process, rewards/incentives for innovation, acceptance of risk if innovative products/services do not succeed, corporate culture fostering creativity, etc.

### **Forms/Types of Innovation**

The importance of interdependencies among partners of the entire supply chain is important in understanding innovation in the agricultural sector (Bröring, 2008). These supply chain interdependencies suggest questions such as:

- 1) What types of innovations are typical in the food and agricultural sector?
- 2) Which business climates and firm characteristics are conducive to each type of innovation?
- 3) What are the structural implications of disruptive innovation (concentration, redefining industry boundaries, etc.)?
- 4) How does idea generation work for systemic innovations that affect the entire supply chain?

From a value chain perspective, innovations in the agricultural sector may include new food products; new end-uses of agricultural raw materials in the energy/industrial and pharmaceutical industries as well as the nutrition industries; new agricultural inputs including biotechnology and

information based technologies as well as enhanced fertilizer, seed, chemical and machinery inputs; new services including enhanced traceability and quality management systems; risk management systems as well as technology forecast services. Moreover, the agricultural sector is rather specific with regards to its governance structures; hence, innovations can also be a result of new governance structures such as contract production, strategic alliances, licensing agreements and joint ventures. Furthermore, regulation plays an important role for the food and agricultural sector. The launch of really new products in the food area can be a lengthy process due to a detailed risk assessment (e.g., it took Unilever about 10 years to launch its functional food margarine Becel pro active). Looking at recent food scandals, the issue of traceability is a also special. This holds especially true for the chain of animal-derived food products, where innovations present an input factor for many partners down in the chain. The public sphere also plays an important role for food and agri sector which may hamper the adoption rate of new technologies (e.g. green biotechnology in Europe) or may result in new obligatory production standards (e.g. carbon foot prints as a measure for reducing greenhouse gas implications of food production).

These particularities require a more detailed look at the classification of innovations. A recent study by researchers of the Wageningen University on innovations in the livestock industry argues that one has to distinguish innovations into those improving the quality of production (e.g. reducing greenhouse gas emissions) and those focusing on product quality. Hence the simple distinction of innovations in process and product innovation may not be adequate. How should one classify a product innovation (e.g. improved enzymes to increase the feed conversion ratio in meat production to reduce phosphorous output of animals) that improves the entire production chain of food products?

### **Organizing Innovation**

As noted earlier, intra-firm processes are critical to the success of innovation. This leads to questions such as:

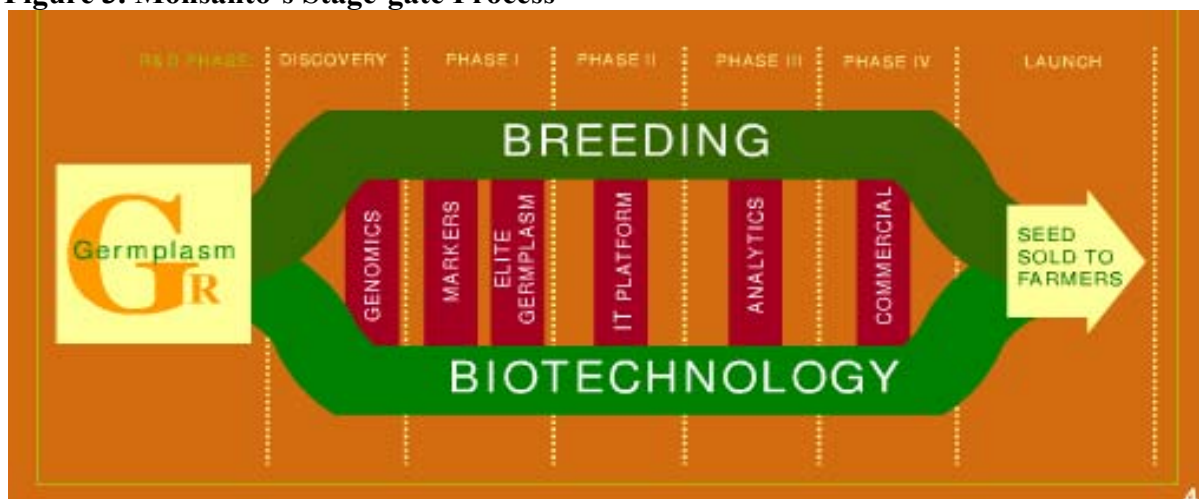
- 1) How does one stimulate creativity and innovation within an organization? In the individuals of that organization?
- 2) What procedures/processes can be effectively used to identify and explore new innovations? How to balance the budget between maintenance/immediate innovation (in reaction to the competition) and truly new innovations?
- 3) Are the criteria that are taken into account to select innovation different in the F&A sector?
- 4) What kinds of innovations have the potential to exploit modularity?
- 5) What is the role of open innovation for innovations in the agricultural sector?
- 6) Which industries can companies in the F&A sector successfully collaborate with in projects dealing with converging technologies and/or markets?

At the origin of the innovation project is the development of an idea. Developing a lot of ideas, the right ideas, and truly radical ideas require a set of people, a certain culture, and some would argue a certain governance structure. Once ideas are generated, successful companies will need to have a process or set of procedures to identify those ideas and select the most promising ones. To fulfill this task, big multinationals in the agricultural sector are using the Stage-gate process

or some variant of it (see Figure 3). Smaller companies do not always use a formal process to select and implement innovation. In addition to following a process, clear criteria must be identified to determine what the best ideas look like. Given the particularities of the food and agricultural sectors, are those criteria different or is the magnitude of the criteria different than in the typical management literature. For example, given the long production cycles, the slow growth markets, the traceability and food safety requirements; is time to market an important criterion in the F&A sector? Furthermore, how does the F&A sector align the need to select the right innovation with the need to select the right set of innovation. In other words, how does the F&A sector manage its portfolio of innovation? What are the criteria?

Organizing innovation is further complicated by the extensive needs and capabilities a company needs to develop a new innovation. In many cases, the capabilities are not all in the hands of one company requiring the leading company to buy other companies and their capabilities or to partner with them. Choosing the right governance structure, choosing the right target companies, successfully implementing a partnership and a merger and acquisition requires skills (Roucan-Kane et al., 2009; Roucan-Kane and Boehlje, 2009). This process is even harder to complete for converging technologies and/or markets.

**Figure 3. Monsanto’s Stage-gate Process**



Source: Monsanto’s web site

### **Portfolio and Risk Management**

Concerns about managing the innovation portfolio leads to the following research questions:

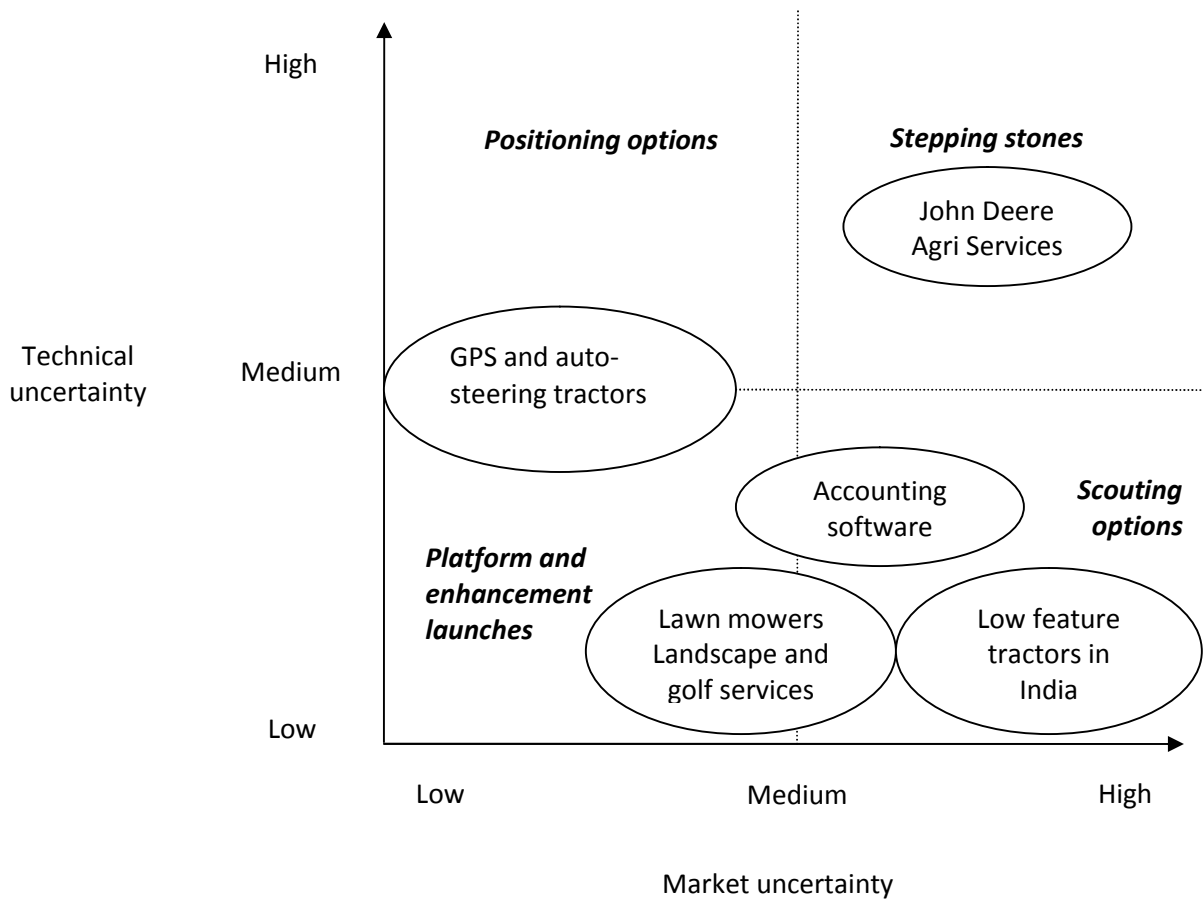
- 1) How does one determine the appropriate portfolio of innovations to fund/support, and manage that portfolio over time?
- 2) What strategies could be used to manage the market acceptance/ adoption and the technical/technological uncertainties of exploring and exploiting innovations?
- 3) What business model/governance structure is most effective to explore innovation? To exploit innovation?

Recent work to evaluate the technical and market uncertainties of innovation and new venture selection by Deere and Company illustrates one approach to the portfolio management problem. Figure 3 graphs Deere’s innovation projects along the dimensions of market and technical

uncertainty to determine how to mitigate the risk, whether risk is being diversified and how the portfolio of innovations evolves over time. Market and technical uncertainties are scored using the scorecards developed by McGrath and MacMillan (2000). McGrath and MacMillan (2000) map the various innovations or new ventures in terms of market and technical uncertainty, therefore highlighting five categories of innovation. Innovation through positioning options creates the right to wait and observe and represents projects looking at servicing under-served customers and non-customers. Innovation through stepping stones options gives low-risk access to potentially high upside opportunities. Innovation through scouting options can be seen as entrepreneurial experiments and as potentially serving non-customers. Innovation through enhancement launches represent improvement to make today's product faster, better, or cheaper. Finally, innovation through platform launches consist of establishing the company in a leading position, ideally in an emerging area with strong growth potential – next generation advantages and represents projects looking at servicing over-served customers and non-customers (McGrath and MacMillan, 2000).

John Deere's GPS auto-steering tractor's project (Gray, Boehlje, Amanor-Boadu, and Fulton, 2004) has low market uncertainty with medium technical uncertainty (Figure 3). A strategic efficiency analysis suggests an in-house activity or tight governance structure based on John Deere's strong capability in machinery manufacturing and commercialization and a potential for sustainable competitive advantage. John Deere's partnership with Home Depot to sell lawnmowers (Home Depot, 2002) is a venture with low technical uncertainty and medium market uncertainty that reaches under-served customers. It's also an example of a business model used to limit risks, opens the door for a potential source of sustainable competitive advantage, and for John Deere to obtain commercialization capability from Home Depot with respect to sales to non-farmers. John Deere's joint venture and later acquisition of an Indian tractor manufacturing company (John Deere, 2005) is a business model example for an innovation with low technical uncertainty targeting non-customers and therefore fairly high market uncertainty. The joint venture was used initially because of the definite potential for competitive advantage, but the lack of commercialization capability in this market from John Deere. As the market uncertainty was resolved and John Deere gained capability, an acquisition replaced the joint venture. The merger agreement for John Deere to acquire LESCO, Inc. (John Deere, 2007) is an illustration of John Deere's strategy reaching non-customers in the professional landscaping and golf course environment. The low technical uncertainty and medium market uncertainty have been limited by the decision to merge instead of create/build. Through this merger, John Deere opened doors to a new market with potential for competitive advantage while gaining capabilities in this new industry by merging with another company. John Deere's consolidation of former units and its acquisition of GeoVantage to form John Deere Agri Services (Laws, 2006) is an illustration of John Deere's strategy to reach under served and non-customers. The technical and market uncertainties are extremely high and have somewhat been limited by the acquisition of GeoVantage, the experience of former John Deere units and the use of a new distribution network. Through this new division, John Deere is moving into a market with great potential for competitive advantage and is gaining capabilities through a different distribution network and the acquisition of GeoVantage.

**Figure 4. Deere and Company's Portfolio of Innovation Projects<sup>8</sup>**



<sup>8</sup> The size of the circles could reflect the optimal level of investment suggested by the financial analysis, but do not due so in this case.

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