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Production Agriculture as a Knowledge Creating System

INTRODUCTION

Throughout the 1990s, advances in information technology and new uses of that technology have been a constant feature of American society. During that time Internet use has exploded, from being an obscure technology used by a few researchers to an everyday part of life. Within production agriculture, the concept of precision agriculture also has emerged over this time period. This concept has attracted intense media attention and considerable interest of leading producers and agribusiness managers.

Because precision agriculture has several dimensions, is novel and emerging, and has received considerable media attention, the concept is not well defined. Although the term "precision agriculture" is now familiar throughout the sector, a specific, common definition does not exist. A recent report by the National Research Council (1997, p. 2) refers to precision agriculture, "... as a management strategy that uses information technologies to bring data from multiple sources to bear on decisions associated with crop production." Key technologies and practices included within precision agriculture are:

- Georeferenced information;
- Global positioning systems;
- Geographic information systems and mapping software;

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- Yield monitoring and mapping;
- Variable-rate input application technologies;
- Remote and ground-based sensors;
- Crop production modeling and decision support systems; and
- Electronic communications.[1]

This article employs a similarly broad definition when referring to precision agriculture. This structure is attractive because it is comprehensive and recognizes the potentially critical role of electronic communications.

Despite the general optimism regarding precision agriculture, considerable uncertainty exists regarding 1) the market forces and justifications that will fuel adoption and general implementation of precision agriculture and 2) the implications of widespread adoption (if it occurs) on market structure. The purpose of this article is to employ key economic and strategic concepts to evaluate those uncertainties. In particular, the article's following four sections will:

1. identify three key economic and strategic concepts relevant to this analysis;
2. use those concepts as a strategic lens to examine the future evolution of precision agriculture;
3. consider effects upon the broader food and agricultural sector; and
4. propose implications for farm and agribusiness decision makers.

Strategic Perspectives

The increasing use of information in today's economy is well chronicled. Numerous articles extol the virtues of information technology in redefining markets and industries. However, as many articles could be found bemoaning the costs, in financial and organizational resources, of the application of information technology. This section will briefly review key analytical studies of the impacts of information technology and then will present economic and strategic concepts relevant to the issue.

Experiences from the Marketplace

Although much of the attention devoted to marketplace effects of information technology has been anecdotal in nature, careful scholarly analyses have recently become available. These efforts have provided a number of key findings. Central among those findings is that learning is an important element of the process. Learning, in this context, includes discovering the indirect effects of the technology (and the information captured in its use), as these effects often are more extensive than the initial direct effects. This leads to the classic S-shaped adoption curve, where the technology is available for a relatively long period and then an apparently sudden burst of adoption occurs. Anticipating *when* that burst of adoption will occur is a particularly important challenge for managers.

The adoption of information technology and its use often attracts media attention. And the early success of major implementations, such as introduction of the Sabre System by American Airlines, sets a tone that leads to overly optimistic reporting of success (Buday, 1986). This rather uncritical reporting actually heightens the manager's difficulty in evaluating technology of this type by disguising the planning and implementation difficulties that often are part of the actual experience (Clemons, 1991; Leonard-Barton, 1995).

Fortunately, rigorous analyses of the implementation processes and effects of the use of information technology are becoming available. Peffers and Dos Santos (1996) provide an analysis of the introduction of ATM machines across 2,534 U.S. banks over the period 1974 to 1986. Interesting among their findings are 1) the presence of adoption patterns that can be best described as exponential or logistic in form, 2) the need to conduct longitudinal analyses to estimate the full benefits of the technology, and 3) that the benefits tended to accrue differentially to early adopters.

Hitt and Brynjolfsson (1996) analyzed 397 large U.S. firms for the period 1987–1991. Their analysis successfully linked spending on information technology to increased productivity and to increased consumer value. However, overall industry profitability tended to be unchanged. This suggests that information based technologies may in the long run be more like strategic necessities than sources of differential sustainable advantage (Floyd and Wooldridge, 1990; Kettinger, Grover, Guha, and Segars, 1994)

The findings of Powell and Dent-Micallef (1997) support this notion. Their analysis of the U.S. retailing sector indicates that adoption of information technology alone is not sufficient to explain differential firm performance. Instead success tends to accrue to firms who leverage information technology with their intangible, complementary human and business resources. These results indicate that information technology adoption may be consistent with a resource-based view of strategic management (Barney, 1991; Rumelt, 1987).

Conceptual Foundations

As physicist Niels Bohr has said, "Prediction is extremely difficult. Especially about the future." (Burke, 1995, p. viii). However, it is useful to attempt to understand market and technological forces employing solid concepts based upon economics and strategy. This section will briefly discuss three such concepts that will be employed as a lens to consider the future evolution of precision agriculture.

Schumpeter and Creative Destruction

The preponderance of economic analysis has focused on stability and attaining equilibrium. Keynesian macroeconomics and neoclassical theory of the firm have provided important understanding both at the policy and decision maker levels. However, those approaches are challenged to explain the dynamically changing economy that faces today's agricultural decision makers.

An alternative perspective to "economics as equilibrium" has received much attention recently. The writings of Schumpeter (1950) emphasize that the role of capitalism is not to achieve some comfortable and stable equilibrium. Instead this approach asserts that capitalism, by its nature, promotes economic change, including structural change in markets and industries. Structural change can emanate from a number of sources including new consumer goods, production methods, and marketing systems. The resulting concept of creative destruction emphasizes that the seeds of change reside within all economic systems; even those that are successful.

Indeed the Schumpeterian perspective stresses the incessant nature of forces for change. Therefore, even though commodity agriculture has a successful history in terms of providing large quantities of safe, affordable raw materials to the food industry, its very success provides the platform to seek out technologies and innovations to better serve food consumers.

Nonaka and Takeuichi and the Knowledge Spiral

Knowledge creation and knowledge management have become managerial buzzwords of the 1990s. Nonaka and Takeuichi (1995) provide a particularly useful evaluation of the process by which firms employ systems to generate decision relevant knowledge. Central to their analysis is the identification of two types of knowledge and the realization that the interaction of both types is critical to knowledge creation. Explicit knowledge refers to knowledge that is transmittable in formal, systematic language. Definitions, equations and theories in journal articles and textbooks are examples of explicit knowledge. Structured educational experiences typically emphasize the value of explicit knowledge.

Nonaka and Takeuichi (NT) make an important contribution by stressing the key role of tacit knowledge in the business processes. Tacit knowledge refers to the "mental models" that all decision makers possess of "how the world works". Tacit knowledge also can be thought of as know-how, experience and skill that we all use.

NT emphasize the interactive role of both explicit and tacit knowledge and stress that managers should define systems and processes to intensify the effectiveness of these interactions. When effective, such systems result in the knowledge spiral depicted in Figure 1. This figure stresses the interaction of explicit and tacit knowledge types. The upper left-hand quadrant, labeled

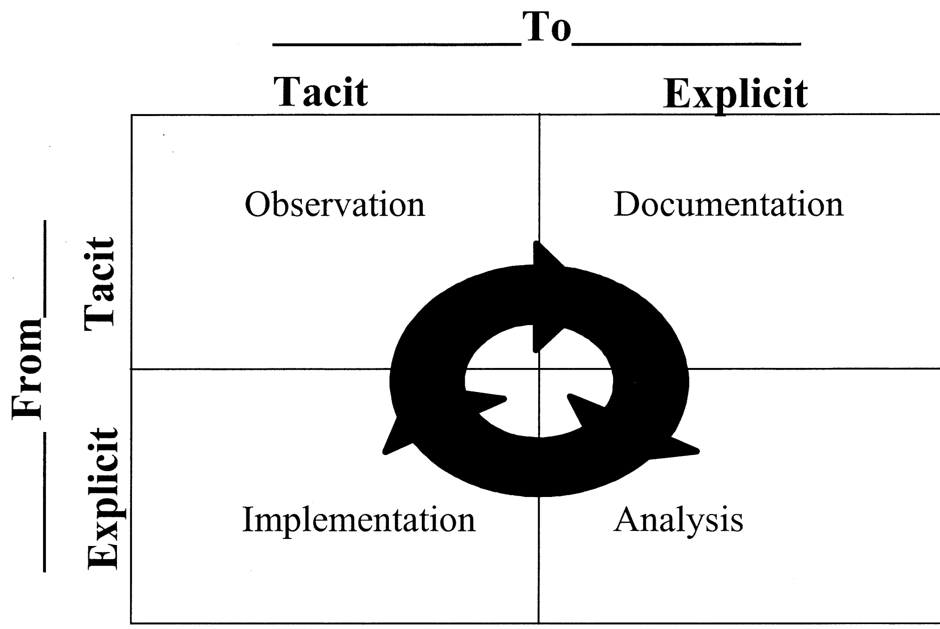

Figure 1. Knowledge Convernsion in a Knowledge Creating System

observation, focuses on the decision maker's ability to recognize problems and opportunities, often from subtle, non-written cues. The experienced manager (whether a farmer or a food processing plant manager) who seemingly can sense that performance problems exist even when they are invisible to others exemplifies this tacit, observation phase. The documentation (upper right-hand) quadrant recognizes that tacit observation by itself often is insufficient. The process of making tacit knowledge explicit, which occurs in the documentation phase, is necessary for effective communication but this step also results in clarification of the situation. The lower right-hand quadrant, analysis, refers to the type of intensive study and investigation that we typically assign to analytical problem solving and research. The fourth section of Figure 1, labeled implementation, recognizes that there are tacit knowledge creation opportunities associated with the application of recommendations and technologies that result from formal analysis.

The circular set of arrows shown in Figure 1 illustrates the knowledge spiral concept advanced by NT. Their analysis emphasizes that effective knowledge creation (similar to Senge's [1991] organizational learning) is a continual process, incorporating both tacit and explicit knowledge. NT conduct their analysis in the context of the individual firm. However, this framework is relevant at the market and industry level as well. Indeed the knowledge spiral of Figure 1 appears, at least partially, to explain the historic effectiveness of the Land Grant university /U.S. Department of Agriculture research/extension system in U.S. agriculture.

Sampler and the Redefinition of Industries

Extensive use of information technology has redefined industries throughout the economy. Although the effects often have been described in some detail, the underlying mechanisms that fuel industry transformation are less well understood. Sampler (1997) provides an important analysis of these underlying mechanisms. His analysis stresses that, although industry transformation may be the result, we need to understand the impact of information technology at the level of the individual transaction. Based upon Sampler's analysis, two key transaction characteristics are identified:

- Separability refers to the extent to which specific information attributes can be captured in association with each transaction and
- Aggregation potential refers to the extent to which those information attributes can be leveraged to gain economic value beyond the purpose of the original transaction.

Traditionally an economic transaction is perceived as the exchange of a good or service for cash. The information attributes that *must* be captured for such an exchange are relatively minimal; the amount of cash and the quantity of the product. Clearly the introduction of low cost information systems has materially altered the nature and amount of attributes that are routinely captured in many of today's economic exchanges. Considerable effort is now expended to identify the purchaser, to profile that purchaser in terms of a host of demographic dimensions, and to provide a detailed depiction of the purchase situation itself.

But information technologies are now being employed in settings that require us to alter our perception of what an economically relevant transaction is. Real time sensors can monitor engine performance or tire wear, for example. When equipped with communication capabilities such monitors can alert decision makers of the potential for critical problems before these problems occur.

The second transaction characteristic is aggregation potential. Knowing the purchase habits of one consumer is interesting but there is relatively little economic value that can be gained from that information. However, being able to accumulate and analyze the purchase behaviors of many consumers can have considerable value. In the case of a sensor tracking engine performance, there is value (which is at least greater than the cost of employing the sensor system) in knowing the status of that one engine. Again, however, there are additional benefits available if that data can be accumulated, analyzed, and used to predict and enhance future performance. These examples illustrate the key role of the aggregation potential characteristic as the use of information technology redefines industries.

Aggregation potential typically requires sophisticated analysis, extensive communications and the ability to capture returns from wide-spread application of the algorithms defined. As detailed by Shapiro and Varian (1999), these characteristics result in significant economies of scale on the "supply-side" of information economics. First-mover advantages, therefore, accrue to the first firm to effectively create a system that can exploit aggregation potentials.

Synthesis of Concepts

Although presented as three individual concepts, the ideas presented in the preceding subsections can be effectively linked together.

- The separability and aggregation potential characteristics of Sampler's analysis have interesting comparability to the tacit and explicit knowledge concepts of NT. Prior to the extensive availability and application of information technologies, decision makers observed many of the attributes that are now separable through technology use. Therefore, application of information technology allows mangers to make explicit many information attributes that previously were only tacitly available.
- The analysis component of the NT knowledge spiral and the aggregation potential transaction characteristic similarly are interrelated. Advanced information technologies allow analysis in greater depth and with more timely application than ever before. The documentation and implementation phases of the NT knowledge spiral are fueled by the capabilities of today's electronic communication capabilities.
- The validity of Schumpeter's philosophy of the incessant nature of change in capitalistic systems has been reinforced as information technology has redefined industries throughout the economy. A key strategic question for agricultural managers is how those forces of creative destruction will unleash themselves in the food and agricultural sector.

Information Technology in Production Agriculture

As noted previously in this article, the precision agriculture concept relates to several technologies and their potential application in a number of production practices. More detailed discussions of these technologies and applications can be found in numerous other sources (Pierce and Sandler, 1997; Robert, Rust, and Larson, 1996). The next segment of this discussion will explore precision agricultural practices through a lens that joins transaction separability and NT's process of converting tacit to explicit knowledge.

Much of the discussion of precision agriculture focuses on the direct effects; emphasizing more specific input application and associated potential cost reductions and/or yield increases. The more strategic focus advanced here, however, identifies the potentially critical role of electronic data capture inherent in these practices. From this strategic perspective, we can see that these precision agriculture practices satisfy the separability characteristic of Sampler's framework.

The use of precision agriculture allows information that formerly was only available tacitly to now be available explicitly. The crop yield monitor is an interesting illustration of this point. Crop farmers are, and probably always have been, passionately interested in knowing how their own crops are yielding. Conversations among farmers during harvest typically include a discussion of yields. Historically numerous clues were employed; such as how many "rounds" it took to fill a wagon or the sound of the combine engine. The knowledge created was tacit in nature but the judgments formed by that knowledge influenced future decisions. The use of yield monitors now provides that information in an explicit form.

But separability and explicit information availability are only part of the strategic framework defined here. Aggregation potential must exist so that the knowledge spiral can be effective. The geographic dispersion and biologic uncertainty inherent in production agriculture suggest that it may be difficult for the individual producer to aggregate information and to perform the sophisticated analysis required to achieve the knowledge spiral that ultimately might be available. New tools are needed to achieve those goals.

Electronic communications and the Internet are affecting activity throughout the economy, allowing aggregation potentials to be exploited and by fueling the knowledge spiral. Adoption of these technologies in production agriculture currently lags behind the sectors that are most advanced in this area. However, that doesn't necessarily mean that such adoption will not occur in the future. For example, production contracts for identity preserved grain are being communicated and executed over the Internet via the OSCAR (Optimum Sales Connection And Resource) system (Optimum Quality Grains, 1999).

Another indication of the potential for use of these technologies in production agriculture is provided by the Cyberfarm experience. (More detailed discussion of Cyberfarm is available from Sonka and Coaldrake [1996].) Cyberfarm is an Internet web site created by a group of Illinois farmers and local agribusiness managers. The group's goal is to identify what capabilities that they would like to see this technology provide to improve their business performance.

Meeting informally over the last three years, the group has identified a number of applications that they see as relevant and potentially valuable to them. For example:

- "Posting" yield maps to web sites so that crop consultants and advisors can examine and evaluate that information in preparing recommendations for future action.
- Preparing a land-owner's diary web site, where landowners (who often do not reside in the local area) can be kept informed about weather, production and marketing conditions on an on-going basis.
- Having crop scouts take digital photos of problem areas in fields that then can be communicated to producers on web sites; so that the producers might be able to decide upon actions without physically visiting the site.
- Being able to retrieve transaction data from elevators regarding quantities and quality conditions of grain delivered by the producer.

Although only a few of the applications identified by this group, these illustrate that communication between producers and their suppliers, advisors, and customers is perceived as a high priority need. This should not be surprising because these applications are analogous to important applications of information technology in other sectors.

The Cyberfarm applications are intriguingly consistent with the aggregation potential characteristic identified previously in this paper. The Internet and electronic communications, as illustrated in the Cyberfarm experience, offer the capability to aggregate information from production agricultural sites at much lower cost than ever before available. This means that the analysis function of the NT knowledge spiral can be based upon data from actual farm operations.

This could be a breakthrough of monumental proportions. Throughout the manufacturing sector profound improvements have occurred when systems were implemented that could effectively employ data from their own operations to learn how to reduce costs and improve quality (Crosby, 1979; Deming, 1986). As mentioned previously, rigorous analysis of the transformation of the banking and retail sectors documented that simply using information technology to capture data provided minimal advantage to firms (Peffers and Dos Santos, 1996; Powell and Dent-Micallef, 1997). Rather it is through analysis of aggregated data and effective use of that new knowledge that competitive advantage is gained.

Possibly similar advances await production agriculture. However, it has not been documented that the benefits of aggregation will be sufficient to effect such change. Further discussion of this topic will be provided in the next section.

A Knowledge Creating Agriculture

Just as it was critically important to examine adoption of information technology across the economy to obtain insights relative to the evolution of precision agriculture, it also is useful to consider changes occurring in the non-production

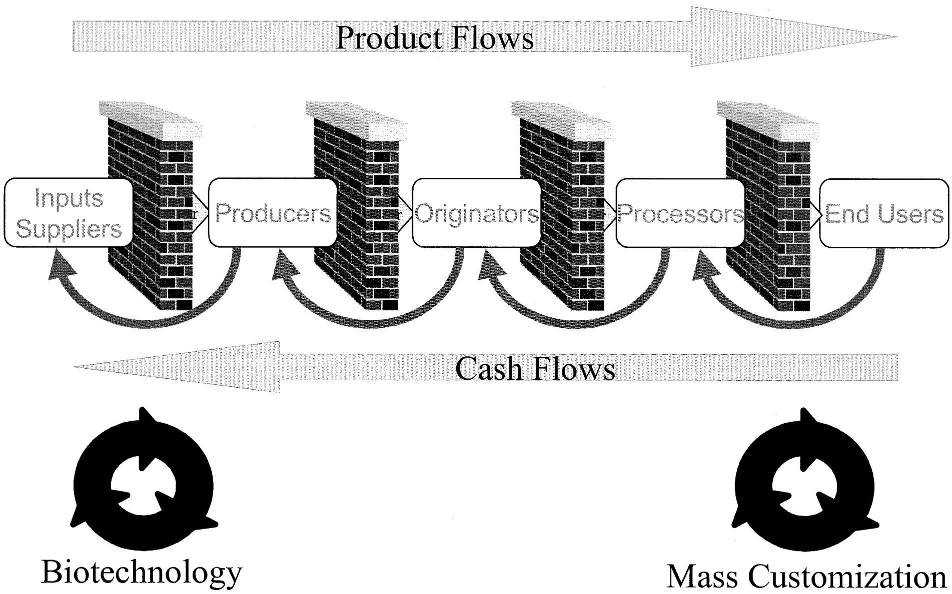

Figure 2. The Evolving Agricultural Value Chain

segments of the agricultural value chain. This section will consider these broader sector dimensions.

Figure 2 depicts the agricultural value chain as comprised of five segments; from genetics to consumers. In this figure, physical product is shown as flowing from left to right with cash flowing from right to left through the sector. Feedback information, however, is shown as flowing only from one subsector to the next.

The commodity nature of the sector is visually depicted with brick walls drawn between each segment. This commodity orientation has important implications. First the capability to coordinate a large and diverse sector such as agriculture with minimal information flow throughout the sector has been a major strength. This is one reason that American agriculture has been successful. However, one side effect of this structure is that knowledge creation tends to be concentrated within each segment in the chain rather than across the chain.

Another feature of Figure 2 is the notation of knowledge creation through the use of information technology that is occurring in the sector. Downstream in the sector (towards the right edge) technologies are being employed to provide consumer offerings that are ever more finely tuned to meet the desires of ever smaller consumer segments. The phrase, mass customization, describes this trend. Here the goal is to provide products and services that are customized to meet specific consumer needs but at the low cost levels formerly available only through mass production. Information technologies and practices discussed previously in this article are critical to these developments.

At the very upstream edge of the sector (towards the left side of Figure 2), profound changes also are occurring. Clearly the advent of biotechnology and the initial widespread adoption of genetically modified crops has been well documented (Hayenga, 1998). Interestingly, Sampler's framework of transaction characteristics appears applicable here as well. The relevant transaction can be thought of as passing genetic characteristics from one generation to the next. Therefore today's advances in biotechnology techniques can be conceptualized in terms of the specificity of the information that is being transferred. Or in Sampler's terms, we're now able to explicitly separate more information attributes with each transaction. Further the area of bioinformatics focuses on the identification of potentially valuable sequences across phenomenally large and diverse data sets; analogous to the aggregation potential concept.

Figure 2 shows two large knowledge spiral circles to depict the influences of mass customization and biotechnology. This depiction highlights the gap existing at the level of production agriculture. As noted by Schumpeter, capitalism exists to creatively destroy such economic gaps. At least potentially, precision agriculture (defined to include electronic communications) will provide tools instrumental in filling this gap.

As currently depicted, Figure 2 shows information feedback linkages as connecting contiguous sectors. An important potential of precision agriculture is that feedback can flow from downstream consumers and processors to the farmer. For example, information on the baking quality of wheat from specific fields may allow for enhancing system performance in terms of end user needs.

Managerial Implications

Today's rapidly evolving market and technological forces present numerous challenges to farm and agribusiness managers. Precision agriculture is one of those developments. In the following paragraphs, a number of key managerial implications will be suggested.

Anticipate the interactions of biotechnology, precision agriculture and electronic communications.

As implied in the preceding section, sector-wide application of the strategic concepts defined in this article suggests an important insight. From the viewpoint of knowledge creation, similar forces exist across the sector. Further, advances in biotechnology, precision agriculture, and electronic communications are likely to be synergistic in their application. Indeed three knowledge bases are being created in the sector that have not existed in the past. These relate to biotechnology, precision agriculture, and mass customization for customers and consumers. Interestingly, fully exploiting the potentials of each individual knowledge base requires interaction among the three.

Concentrate on timing and sources of value that drive adoption.

Considerable excitement and enthusiasm exists regarding precision agriculture. However, it's difficult to identify large direct benefits for specific applications. When quantified, the benefits appear to be positive but relatively small. In such situations, it is not helpful to look to econometric analyses of prior data for insights. Instead it is necessary to speculate regarding potential futures, drawing upon conceptual frameworks identified previously.

The Sampler transaction characteristic approach and the NT knowledge spiral suggest a number of important implications:

- Decision makers will strive to make tacit data explicit for transaction elements that are important to them. Therefore adoption of yield monitors is occurring even if direct economic benefits can not be quantified (Nelson, 1998).
- It is likely that aggregation across farm firms will be needed to achieve significant economic benefits.
- Aggregation can provide economic benefits through three means.
- —Enhancing market coordination for farm output;
- —Reducing cost inefficiencies between input suppliers and producers; and
- —Developing new agronomic paradigms to directly improve crop production.
- Interestingly, most attention has been devoted to the third means (agronomic paradigm improvement). However, because of biologic uncertainty and because new research paradigms will be required (National Research Council, 1997), this is the most difficult of the three approaches and likely will require several years before improvements will be forthcoming. Conversely, market coordination benefits and cost reductions do not require new science to be usefully employed. Instead, communication and novel sector linkages have been the key missing links to enhance performance in these areas.

Manage intangibles as they become increasingly important.

Historically, control of physical assets has been of critical importance in production agriculture. The quality and amount of land, livestock, buildings and equipment have been, are, and will continue to be key factors affecting farm profitability. However, all three concepts noted previously (Schumpeter's creative destruction, NT's knowledge spiral, and Sampler's transaction characteristics) stress that intangible, knowledge-based assets will become increasingly important in the future.

If precision agriculture and electronic communications enhance sector coordination and performance as suggested in the prior sections, the most effective managers will need to enhance their skill sets to include management of intangibles. Doing so is likely to include actions such as the following:

- Building information linkages and relationships across the sector value chain;

- Actively enhancing information management capabilities, even if immediate direct economic benefits are not expected to be large;
- Being able to test and evaluate alternative production systems before the effectiveness of those systems is widely known in the market;
- Monitoring economic and market developments across the agricultural value chain and in other sectors; and
- Understanding both the operational and strategic benefits of technologies that create knowledge in the sector.

SUMMARY

In the last decade, radical advances in the availability and capability of information technology have made substantial impacts on society, partially through redefinition of numerous economic sectors. Within production agriculture, precision agriculture (here thought of as a suite of technologies that includes electronic communications) has attracted considerable attention and interest. However, despite widespread enthusiasm, significant uncertainty exists regarding both the processes that would fuel adoption and general implementation of these technologies and the implications of widespread adoption (if it occurs) on the structure of the agricultural system.

Based upon lessons learned in other sectors of the economy, this article highlights key economic and strategic concepts that can frame the evaluation of information technologies. These concepts are employed as a strategic lens to examine the future evolution of precision agriculture with special attention paid to potential effects upon the broader agricultural and food sector.

Much of the popular media attention and academic research focused on precision agriculture to date has emphasized operational effects at the level of subparts of the individual farm field. These direct effects are, of course, important. The framework advanced in this paper illustrates, however, that the more profound impacts of information technology adoption typically occur at the industry or sector level.

NOTE

1. Of Course, a producer practicing precision agriculture need not necessarily be using all the practices noted.

REFERENCES

Barney, J. 1991. “Firm Resources and Sustained Competitive Advantage.” *Journal of Management, 17*: 99–120.

Burke, J. 1995. *Connections.* New York: Little, Brown and Company.

Buday, R. 1986. “Sabre Gives the Edge to American Airlines.” *Information Week, 26* : 34–35.

Clemons, J. 1991. “Information Systems for Sustained Competitive Advantage.” *Information Management, 11*: 131–136.

Crosby, P. 1979. *Quality is Free.* New York: McGraw-Hill.

Deming, W. E. 1986. *Out of Crisis.* Cambridge, MA: MIT Center for Advanced Engineering Study.

Floyd, S., and B. Wooldridge. 1990. “Path Analysis of the Relationship between Competitive Strategy, Information Technology, and Financial Performance.” *Journal of the Management of Information Systems, 7*: 47–64.

Hayenga, M. 1998. “Structural Change in the Biotech Seed and Chemical Industrial Complex. *AgBioForum,* 1(2), 43–55. Available at: http://www.agbioforum.missouri.edu. Accessed May 6, 1999.

Hitt, L. M., and E. Brynjolfsson. 1996. ”Productivity, Business Profitability, and Consumer Surplus. *MIS Quarterly, 20*: 121–142.

Kettinger, W., V.Grover, S. Guha, and A. Segars. 1994. “Strategic Information Systems Revisited. *MIS Quarterly, 18*: 31–58.

Leonard-Barton, D. 1995. *Wellsprings of Knowledge.* Boston: Harvard Business School Press.

National Research Council, 1997. *Precision Agriculture in the 21st Century.* Washington, D.C.: National Academy Press.

Nelson, M. J. 1998. *A Dynamic Simulation Model on the Diffusion of Yield Monitoring and Mapping Technologies.* Unpublished MS thesis. Urbana, IL: University of Illinois.

Nonaka, I., and H. Takeuchi. 1995. *The Knowledge Creating Company.* New York: Oxford University Press.

Optimum Quality Grains. 1999. Available at: http://www.optimumqualitygrains.com/. Accessed May 15, 1999.

Peffers, K., and B. L.Dos Santos. 1996. ”Performance Effects of Innovative IT Applications Over Time. *IEEE Transactions in Engineering Management, 43*: 381–392.

Pierce. F. J. and E. J. Sandler, eds. 1997. *The State of Site-Specific Management for Agriculture.* Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Powell, T. C., and A. Dent-Micallef. 1997. Information technology as competitive advantage. *Strategic Management Journal, 18*: 375–405.

Robert, P.C., R. H. Rust, and W. E. Larson, eds. 1996. Proceedings of the Third International Conference on Precision Agriculture. Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Rumelt, R. 1987. “Theory, Strategy and Entrepreneurship.” Pp 137–158 in D. Teece, ed., *The Competitive Challenge.* Cambridge, MA: Ballinger.

Sampler, J. L. 1997. “Redefining Industry Structure for the Information Age.” *Strategic Management Journal, 19*: 343–356.

Schumpeter, J. R. 1950. *Capitalism, Socialism, and Democracy.* New York: Harper & Row.

Senge, P. M. 1990. *The Fifth Discipline: The Age and Practice of the Learning Organization.* London: Century Business.

Shapiro, C. and H. R. Varian. 1999. *Information Rules.* Boston: Harvard Business School Press.

Sonka, S. T. and K. F. Coaldrake. 1996. “Cyberfarm: What Does It Look Like? What Does It Mean?” *American Journal of Agricultural Economics, 78*: 1263–1268.