

**Strategic Options and Value Decay in Technology Introduction under Uncertainty:
A System Dynamics Perspective on Dynamic Product Competition[†]**

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[†] Paper prepared for the Forum of the International Food and Agribusiness Management Association, Chicago, IL, June 25, 2000.

Strategic Options and Value Decay under Uncertainty: A System Dynamics Perspective on R&D Investments

L. Martin Cloutier and Michael D. Boehlje

In recent years, firms in the biotechnology industry have intensified their investments in research, development, approval, manufacturing, and marketing of new products to target the specific needs of customers. Whether in the agriculture, health, manufacturing or pharmaceutical industries, biotechnology-related firms engage in dynamic product competition by leveraging knowledge from accelerating discovery rates in genomics. In essence, these firms are increasingly structuring value chains to commercialize their scientific discoveries through various mergers, acquisitions, joint ventures, strategic alliances, and other forms of investment in downstream activities closer to the consumer or end-user.

The underlying economic problem for the investing firm is whether streams of economic quasi-rents in dynamic product competition will create sufficient economic value to justify investments in the initial and in all subsequent undertaking of activities prior to value decay. This economic problem is further complicated by the underlying economic uncertainty. The focus of this discussion is a conceptual framework, a systems dynamics model and illustrative results from this model of the decision problem of choosing a technology platform for introduction and commercialization of new corn genetics or varieties given an uncertain environment and the time delays inherent in transforming R&D investments to commercial products.

Relevant Literature/Concepts

Analysis of the process of innovation and diffusion as well as R&D investments in the

agricultural sector have resulted in important explanations of the aggregate rates of return on investment (Huffman), the economic incentives for the types of technological change (induced innovation as a function of relative resource scarcity) (Biswanger, Hayami and Ruttan), and the scale and structural implications of various types of technology transfer and R&D investments.(Sunding and Zilbermann). Others (particularly sociologists) have looked at the adoption process and the characteristics of various adopters of new innovations. (Rogers) These studies have not focused on the management issues and decision problem of choosing a technology or technology platform and the commercialization of the results of the R&D activity. This work is more commonly the domain of scholars in schools of management.

Maier has conceptualized the diffusion of innovation as a complex time-dimensioned decision problem with challenges of time delays and competitive product or innovation development. In a broader context the sequence of activities from the R&D decision to commercialization involve not only time, but substantial uncertainty. Barney and Lee have argued that uncertainty arises from business environment interactions and ubiquitous long time delays between a series of sequential investment decisions (for example, between product research and marketing). They also point out that economic uncertainty breeds tensions between the transactions cost concepts of minimizing opportunism and the strategic options concepts of maximizing flexibility. These tensions are further exacerbated by the need for firms to establish coordination mechanisms that secure property rights from endogenous learning activities.

It has been posited by Sanchez that the concept of strategic flexibility (that is, strategic options) in product competition represents a fundamental approach to the management of uncertainty.@

The term strategic options refers to a firm's ability to alter decisions about resource access as well as interfirm relationships over time to achieve economic returns in dynamic product competition (for example, dimensions of product competition can be time-to-market and scope). From a management of technology perspective, Sanchez has argued that the dynamic product competition problem can be conceptualized using the reinforcing feedback loop among technologies, product strategies, interfirm coordination mechanisms, and the business environment. But, the examination of the long time delays between sequential decisions that influence the structural dynamic of the feedback loop behavior require empirical inquiry to better understand how economic uncertainty affects strategic decisions over time.

A Mental Model

The choice of a technology platform B traditional breeding programs vs. biotechnology B to bring new crops to market is a complex decision that can be best framed as a dynamic multi-stage decision problem. Figure 1 provides a synopsis of the key components/stages and drivers of that decision problem. This conceptualization identifies the stages of the decision problem as the research and development function, the multiplication (technology transfer) and ramp-up function, and the market introduction and commercialization function. Research and development involves the identification of a particular trait or attribute such as yield, drought resistance, pest resistance, protein content, etc. that is to be enhanced and marketed; and the research activities that result in the isolation, identification and production or expression of that trait or characteristic with sufficient accuracy and certainty that it can be efficiently and effectively reproduced and multiplied under field conditions. This stage also involves obtaining whatever regulatory approvals are necessary such that the results can be transferred to the

next stage of multiplication and ramp-up.

In the multiplication and ramp-up stage, the volume of product obtained from the R&D stage is expanded and multiplied to obtain sufficient volume for commercial sales. The biological growth process imposes both time delays and the natural laws of biology on this ramp-up stage with traditional breeding programs; genetic modification including the opportunities for gene-splicing may alter these time delays and the growth processes when the biotechnology platform is utilized. Once adequate volumes are available for commercial sales, the new product is released to the third stage of market introduction and commercialization. In this stage the new variety is made available to the marketing/sales force, and it is adopted by producers depending upon a number of factors including the availability of competitive products and producer=s expectations of the net benefits of the attribute or variety.

Each stage of the process is impacted by various drivers or influencers that will impact the rate of development as well as the cost and effectiveness of performing the functions or activities in that stage. In the research and development stage, a major determinant of performance will be as noted earlier the technology platform. Traditional breeding programs are characterized by specific cost, efficiency and effectiveness parameter as well as rates of progress or improvement in identifying and isolating specific traits or attributes; biotechnology in general accelerates this rate of advancement, but it frequently does it at a higher cost. Expected benefit streams are a major determinant of which traits or attributes are the focal point of research and development activity, and this expected benefit combined with the availability of funding will also impact the rate and effectiveness of performing the R&D activities. For the biotechnology platform, synergetic product benefits that may be a Aby-product@

from the investment in basic science such as genomic will also have an impact on the domain or the trait category that is the focal point of R&D activity. Synergetic product development may not be as important an influencer or driver in natural selection breeding programs, but with both technology platforms the learning process will be an important determinant of the effectiveness and the speed of the R&D activity. Finally, any regulatory requirements and the speed with which any regulatory approvals can be obtained may be a major determinant of R&D activity; the basic presumption is that regulatory processes will be much more significant in driving research and development using a biotechnology platform compared to a traditional breeding program.

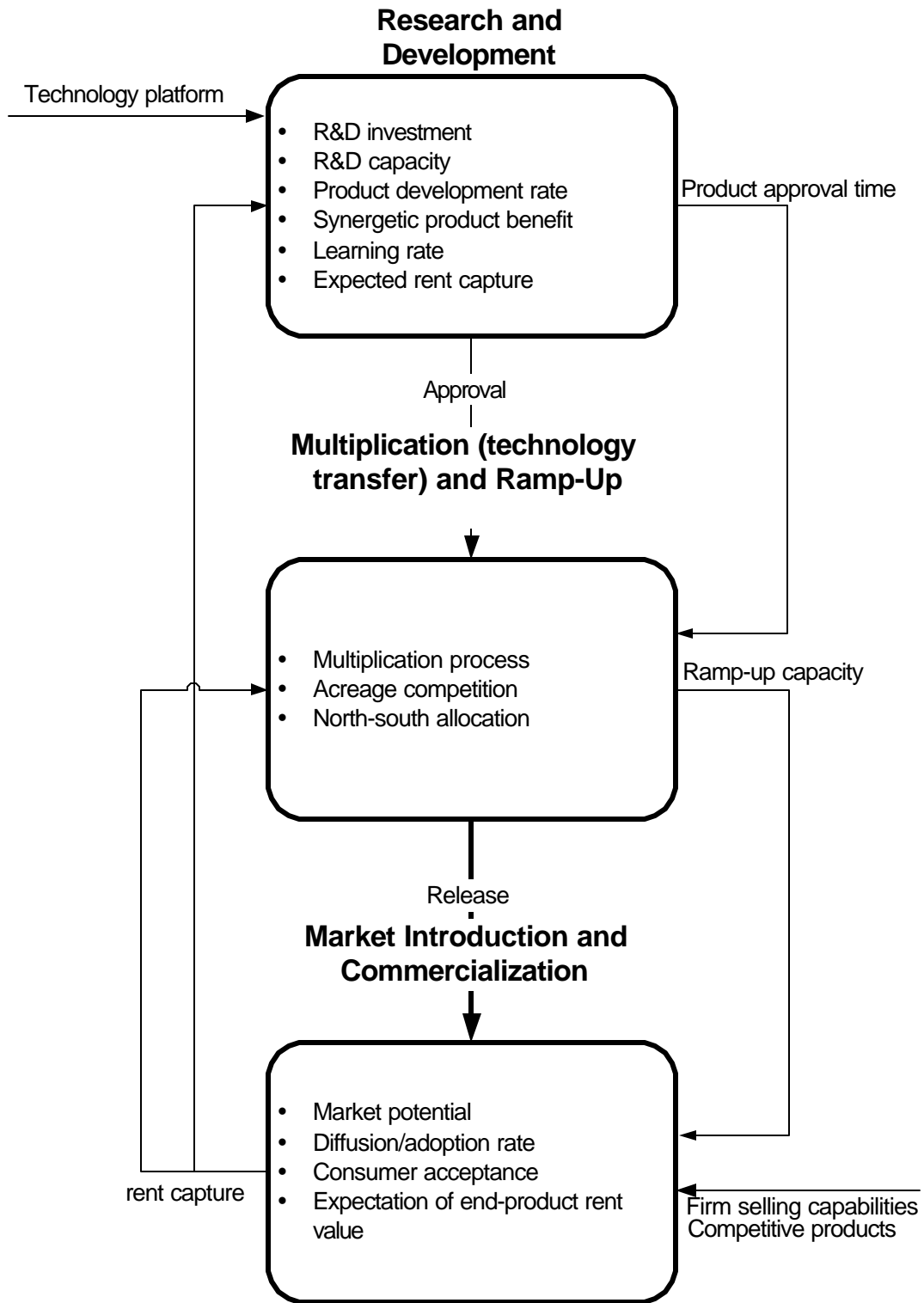
Although the multiplication and ramp-up stage is much more complicated than that depicted in Figure 1, the two major drivers or determinants of the speed, effectiveness and efficiency of this stage are identified as the multiplication rate/process and the capacity to multiply. The multiplication process is in essence the biological and/or biotechnology determined procedure for taking germplasm from the R&D stage and increasing the volume to a level adequate for market introduction. This process is driven by the biological growth process of plants in the case of traditional breeding programs, but with the biotechnology platform it is accelerated through gene splicing and other technologies. The second determinant of capacity to multiply depends on two major decisions: 1) how much acreage is available for seed stock production given that simultaneous with the development of this trait or variety is the development of competitive products that also are demanding multiplication and ramp-up acreages, and 2) is the seedstock production activity constrained to only the northern or southern hemisphere, or are production and information systems in place to accelerate multiplication and ramp-up by producing in both northern and southern hemispheres, thus doubling annual multiplication and ramp-up capacity.

Once a product is released to the marketing and sales organization for introduction and commercialization, its acceptance by producers or end-users will be significantly impacted by producer=s net benefit expectations. These expectations are typically captured in economic modeling through the adoption/diffusion rate and summarized in most cases by an S-shaped diffusion curve. But the shape and characteristics of this curve will be impacted by more than just the net benefit stream of the product or trait resulting from the R&D and ramp-up stages. Adoption will also depend on the performance of competitive products; if an effective competitor has been introduced into the market, the rate of adoption will be substantially reduced. Furthermore, the capability and capacity of the marketing program and the sales force will impact the purchasing behavior of producers and rate of adoption of the new product or technology. Adoption rates and commercialization may also be impacted by perceptions of consumer acceptance of the technological platform; current discussions with respect to consumer acceptance of GMO products and fears on the part of producers that they may not have a market for GMO corn or soybeans may significantly impact their willingness to plant varieties created with this platform compared to those produced with traditional breeding programs. And equally important is the concept of value decay for products that have enhanced attributes such as increased protein content. If it is perceived that this enhanced value will be retained over a number of years, more producers may be willing to make the adjustments necessary to adopt the new technology. In contrast, if rapid value decay is expected such that producers anticipate increased benefits for only a very short period of time, they would be less likely to make transitions and adopt the new product this would reduce the rate of adoption and diffusion.

A Dynamic Numerical Model

Our paper examines the economic issues of dynamic product competition in the agricultural biotechnology area using a dynamic and nonlinear simulation model. System dynamics modeling and simulation can be used as a method of conducting scenario analysis to understand the influence of the uncertainty created by time delays between sequential decisions within the context of dynamic product competition (Coyle, Forrester, Morecroft and Sterman). The simulation results explore and contrast two intriguing cases in agricultural technology introduction. These cases relate to (1) traditional breeding methods (for example, High Oil Corn), and (2) biotechnology-based breeding methods (for example, Bt corn). The simulation explores differences due to time delays, adoption, and diffusion rates and consumer acceptance related to both breeding methods. The traditional breeding method has a longer time-to-market than the biotechnology-based product introduction. Further, the consumer acceptance is specified to represent a higher degree of uncertainty for biotechnology-based products relative to the ones based on traditional breeding methods. The model contributes, via its simulation results, to a deeper understanding of the underlying economic dynamics and describes time-based tradeoffs relative to economic rent capture and value decay.

Figure 1: The Process of Transforming Technology From R&D to Commercialization



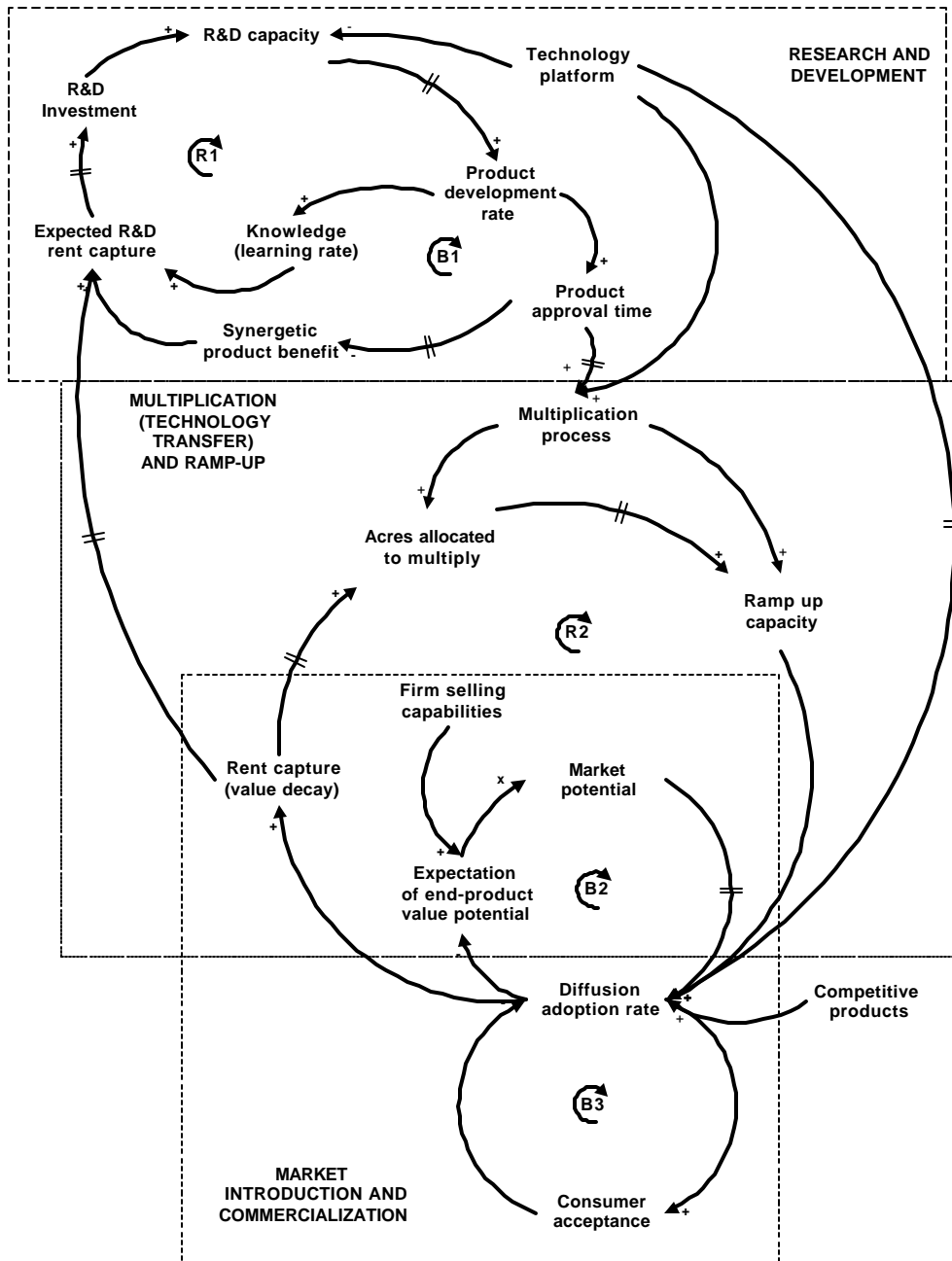
The influence diagram of Figure 2 is introduced to capture the dynamics of the stages depicted in the process represented in Figure 1. The influence diagram is a means to represent the microstructure components responsible for the dynamic and nonlinear behavior of the system. The stages are depicted within their respective dotted line boxes and include the main feedback loops of the entire system to be modeled and simulated. This influence diagram is a simplified structural description of archetypical influences within the system of interest. It is typically used as a “blue print” for the numerical model development.

The R&D stage includes a reinforcing loop (R1) and a balancing loop (B1). The reinforcing loop represents the R&D capacity expansion that occurs as a result of expected R&D rent capture leading to an increase in R&D capacity. Note that there is an explicit time delay between the expected rent capture and the increase in R&D capacity. The R&D capacity is also constrained by the choice of the technology platform. The R&D capacity influences the discovery/invention rate, leads to valuable knowledge and ultimately influences expected R&D rents. The added R&D capacity does not automatically translate into increased discovery/invention rates and in the formal numerical model time delays must be added explicitly. There is an R&D balancing loop due to regulatory approval time delay that opposes the potential for synergetic product benefit, and thus limits R&D rents expectations.

The technology platform, part of the R&D stage, influences the multiplication time process within the multiplication and ramp-up stage. Depending upon the choice, for example, between a traditional breeding versus a biotechnology-based breeding process, the time delay between the multiplication process and the acres planted for seed production will be more or less long or short, respectively. The main reinforcing feedback of the multiplication and ramp-up stage (R2) shows the

acres allocated, influences the ramp-up capacity which then influences the adoption/diffusion rate. The adoption/diffusion rate then influences rent capture and acres allocated.

Figure 2 Influence Diagram: From R&D to Commercialization

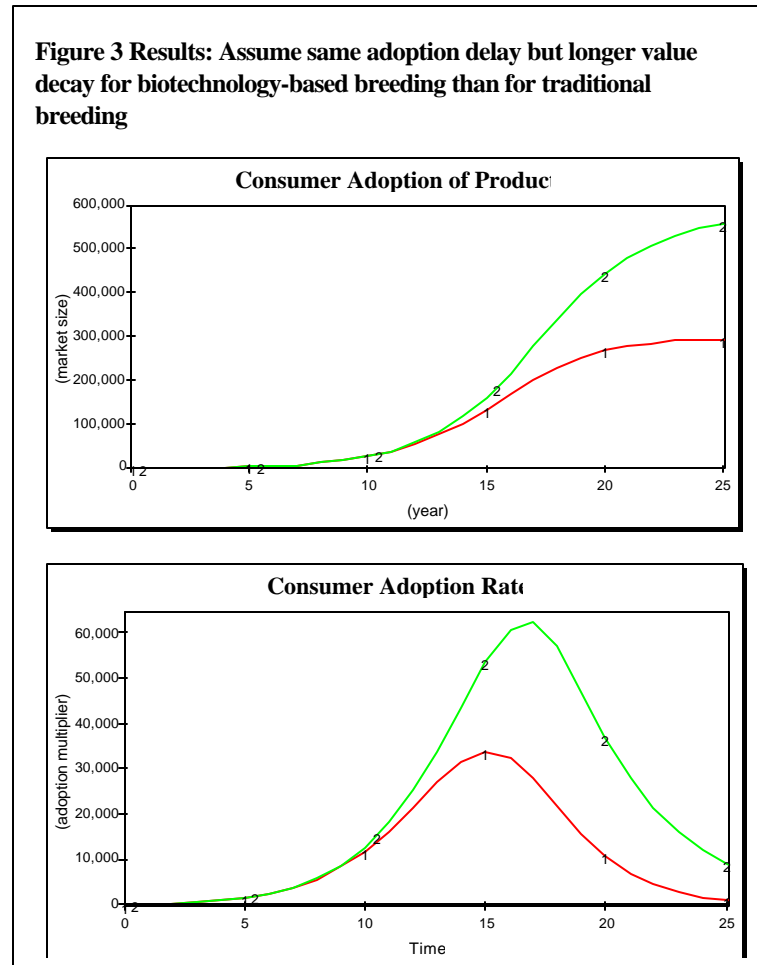


The market introduction and commercialization stage is built around an s-shape adoption curve. This stage contains important feedback loops of its own internal microstructure, and also has influences on the behavior of multiplication and ramp up, and of R&D stages. The first feedback loop (B2) shows the structure of the diffusion/adoption process. The expectation of end-product value, influenced by sales force capabilities and the adoption rate, influences the potential market. The market potential influences the diffusion/adoption rate with a time delay. As the diffusion/adoption rate increases the process eventually slows down because the market potential has been addressed. The diffusion/adoption rate is reflected in the growing number of product users, hence in market acceptance and with a time delay, as seen in the balancing loop (B3). Growth in market acceptance opposes adoption/diffusion rates. The influence diagram also includes an exogenous competitive product factor that limits the rate of diffusion/adoption. The rate of adoption influences rent capture. Rent-capture feeds back to R&D investments with a time delay.

Next comes the presentation of the numerical model. The model presented here is a simplification of the influence diagram presented in Figure 2. Our goal in this paper is to illustrate the process by which the model can be built, used for simulation purposes, and to report illustrative quantitative results using the modeling software visual display capabilities. The model shown below emphasizes the market introduction and commercialization stage of the technology transformation process introduced of Figures 1 and 2, as well as the most critical influences from the R&D and multiplication and ramp-up stages. This model is used to develop results that illustrate the importance of the dynamic and non-linear behavior of the underlying model structure.

The results of three simulations are presented below. The simulations illustrate numerically issues

of tradeoffs between a traditional breeding program and a biotechnology-based breeding program. The first set of results is reported in Figure 3. These results are based on the assumption that the rate of adoption of products based on traditional breeding, versus biotechnology-based breeding, are identical. The difference between the two programs is an expected rent value from the biotechnology-based

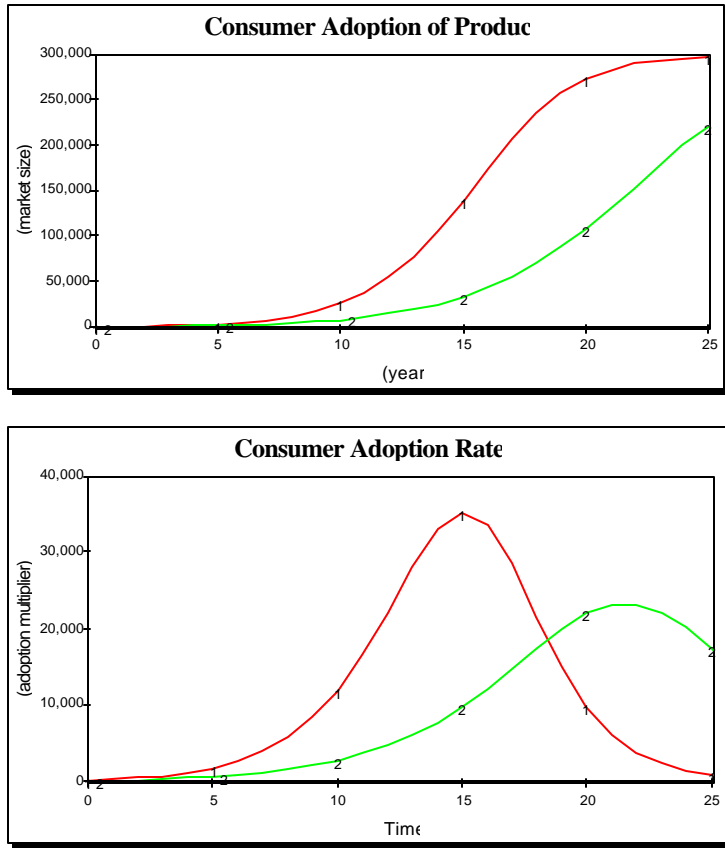


product that extends over a longer period. As seen, the number of consumers and the rate of adoption report greater figures for the biotechnology-based product (see line 2). This result reflects the underlying assumption that the biotechnology platform can be used to replicate products and has slower value decay for consumers.

The next set of results, in Figure 4, shows what would happen if the expected value was the same for

both traditional breeding and biotechnology-based breeding and the adoption time delay of biotechnology-based product was slower. Not too surprisingly, results reports that the product based on traditional breeding (see line 1) leads to a faster and to a more important adoption level.

Figure 4 Results: Assume fastest adoption for traditional breeding than biotechnology-based breeding, and same delay for value decay



The final simulation results, in Figure 5, are based on the simultaneous adoption and value decay assumptions, simulated independently in Figure 3 and 4. First, products of traditional breeding methods are assumed to have a speedier time of adoption than biotechnology-based products and thus the former is likely to have a shorter time of adoption. Second, the products of biotechnology are assumed to have a greater rent potential than traditional

breeding methods as the technology platform allows for longer span of value creation from the product development platform. This set of result shows that path of adoption by looking at these assumptions simultaneously. The path of adoption is actually slower for biotechnology at first (see line 2), but eventually the biotechnology-based product, that has a slower decaying value than traditional breeding (see line 1), creates a larger consumer market in spite of its initial slower adoption rate.

Conclusion

This paper has presented an application of the system dynamics method applied to the problems of

technology adoption/diffusion and of

value decay in the biotechnology area.

In particular, the results presented in

this paper emphasize the importance of

time delays given uncertain effect over

time of the assumptions under

consideration. Time delays are key to

the understanding of the dynamic and

non-linear behavior of systems. Results

from the structure of the market

introduction and commercialization

stage presented here are quite

illustrative. Indeed, the results

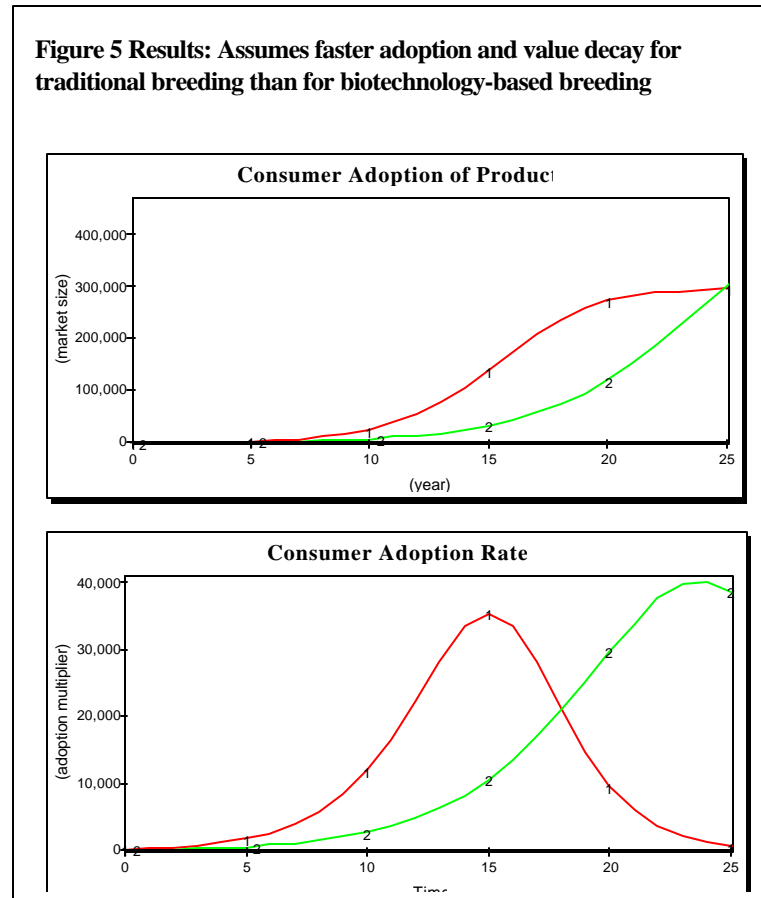
presented in this paper show how this method can be employed by decision-maker to obtain a greater

understanding of key issues prior to committing large amounts of resources so that expectations can be

set at the appropriate level. Some assumptions were made explicit and the model was used to inform

the outcome.

Work is currently underway to detail a comprehensive understanding of the typical time delay assumptions in the R&D and the multiplication and ramp-up stages and of their impacts on the behavior



of the market introduction stage.

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