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MODELING INNOVATION AS A PROCESS OF DESIGN IN EDUCATIONAL BUSINESS
SIMULATIONS

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ABSTRACT

Though appropriate for teaching other business functions, previous methods of modeling innovation in business simulations are not suitable for teaching the management of innovation. This paper presents a new method of modeling innovation in business simulations: students use marketplace data in attempts to solve a combinatorial optimization problem. The essential properties of innovation – unpredictability, surprise, path-dependence, and probabilistic success – are produced. The method also provides means for simulating technological advance and for measuring core competencies and innovation.

INTRODUCTION

Innovation is a potent competitive force. No other competitive force has the power to raise the small firm to industry leadership (e.g., Sony, Xerox, Intel, and Microsoft), or cause the failure, and do so quickly, of an industry leader (e.g., Wang and Philco). To learn how to manage innovation, managers need a ‘practice field’ where they can create and test decision rules and develop the good judgment. Educational business simulations appear to be the ideal means of satisfying these needs. Despite this, current methods of modeling innovation in business simulations cannot represent essential qualities of innovation. This paper presents a new method that properly simulates innovation in educational business simulations.

THE CHARACTER OF INNOVATION

The process of innovation is unique among business functions; it has its own rhythm and characteristics. These are described well in several works (Drucker 1973, 1985; Quinn 1985; Steele 1989; Frey 1994). The most startling characteristic of innovation is its unpredictability. The successful application and design of a product innovation, for example, is rarely predictable at the start of its development. The eventual size of the market for the innovation and the speeds at which the innovation and the market develop are equally unpredictable. This unpredictability is the source of its four other principle characteristics:

High Failure Rate: Even with proper management, only a small fraction of innovative ideas become innovations.

Path-Dependency: Innovation is path-dependent. Path-dependency means that (1) some paths of change will not get from state A to state B while others will (Frey 1994) and (2) the actions one takes today determine the choices one faces tomorrow (history matters).

Surprise: Along the path to success, or failure, lie unpredictable obstacles and beneficial ‘tail winds’. These events surprise management.

Probabilistic Success: When making decisions, there are always more options than resources. Compounding this difficulty, there is never enough information to confidently determine the best options. This situation makes success a matter of probability (Steele 1989).

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A REVIEW OF BUSINESS SIMULATIONS' MODELING OF INNOVATION

Designers of business simulations have recognized the need for incorporating innovation, and have represented innovation in three ways:

Product Quality Representation: In some simulations products purport a value affecting how customers appraise a product (e.g., quality). The demand function takes this value as an argument. In these simulations, an innovation increases a product's value.

Product Attribute Representation: When simulations include product attributes, a product's characteristics determine its value (Teach 1990; Gold and Pray 1998). In these simulations, an innovation either expands the limits of a product attribute or creates a new attribute.

New Product Class Representation: In some simulations, an innovation constitutes the creation of an entirely new market – a technological breakthrough. At such an event, a new demand function is added to the simulation (Pray and Methe 1991).

All three representations use the same method to simulate innovation. Firms attempt innovation by allocating capital to 'research and development'. The allocation purchases a draw from a probability distribution. If the draw exceeds a predetermined threshold, the firm innovates. To aid their decisions, students can purchase technology and marketing reports that indicate the probability of innovating and the market's response to innovation. These reports contain random errors that simulate uncertainty.

With this method, students have limited influence over the probability distribution and threshold parameter. The most potent means of influence is investment in research and

development. Greater investment increases the probability of innovation. This rule also applies to purchasing information. Greater investment buys information that is more reliable.

Though this method is useful for simulations that teach the management of other business functions (e.g., marketing), it cannot teach the management of innovation. There are three reasons:

First, the method does not simulate the process of innovation. The probability distribution simulates the outcome of the innovative process (success or failure). It does not model the process that produces this variation. Because of this, a student using such a simulation does not experience the unpredictable, path-dependent development process of innovation.

Second, the method reduces the management of innovation to an investment decision. Investment in research and development is the primary means through which students influence the probability of innovating.

Third, the method poorly simulates technological advance. Technological advances create a multitude of opportunities and substantially increase uncertainty. The previous method only simulates a small number of new opportunities, specified by the predefined probability distributions.

A NEW METHOD OF REPRESENTING INNOVATION

The Attribute-Characteristic Representation

In the new method, products are composed of attributes that vary *qualitatively*. Each attribute expresses one characteristic from a set of characteristics. With this method, every product is represented by a unique vector of characteristics called a product's *design*. Formally, let a product be composed of n

qualitatively varying attributes. A product's design is specified by the vector (c_1, c_2, \dots, c_n) where c_1, c_2, \dots, c_n are the characteristics expressed by the n attributes.

With this representation, one can easily use characteristics to define sets of products – an important concept in this method. One does this by requiring that one or more characteristics be present (or absent). Three examples of product sets are sports cars, cars with four cylinder engines, and sports cars with four cylinder engines. A set of products defined upon product characteristics is called a *product class*.

Value Functions

A function $V = h(c_1, c_2, \dots, c_n)$ determines each product's value. These values are used to calculate demand using, for example, the Gold and Pray system of demand equations (Gold and Pray 1984). One can understand the type of value function required by asking, "How much does a particular product characteristic contribute to a product's value?" For example, how much value does a red exterior add to the value of an automobile? This question is difficult to answer. The value of a red exterior depends upon an automobile's style. It is highly valued on sports cars but not on limousines. In this example, characteristics expressed by one attribute (style) affect the contribution to product value made by the characteristics expressed by another attribute (exterior color). This effect is called an interaction. Interactions make product design a difficult task because they create *frustration*. Frustration occurs when improving a product in one dimension decreases the product's performance in other dimensions.¹

¹ The value functions used in other simulations containing product attributes do not produce frustration (Teach 1990; Gold and Pray 1998).

The value functions suitable for modeling innovation in business simulations must produce a particular correlation structure among product classes defined on the same attributes.² 'Front wheel drive sports cars' and 'rear wheel drive sports cars' are examples of this important case; these classes are defined upon the same attributes (drive train type and style). If the value function has no interactions, all such cases are highly correlated. As the number of interactions increases, these correlations diminish. With value functions suitable for modeling innovation, some pairs of these product classes will be highly correlated. In these pairs, the attributes that define the difference between the product classes (in the example above: drive train type) will interact with a small number of other attributes. With a suitable value function there will also be some pairs of these classes that are poorly correlated. In these pairs, the attributes that define the difference between the classes will interact with a large number of other attributes.

Value functions producing this correlation structure are found among combinatorial optimization problems. Examples of combinatorial optimization problems include designing the layout of an integrated circuit, finding the shortest tour connecting a set of cities, and finding a protein that catalyzes a particular reaction.

What Types of Products are Useful?

Utilizing this system for 'real' products is problematic. One will confront great difficulty in matching a combinatorial optimization function

² To calculate the correlation between two product classes, one 'pairs' products and applies the standard formula from statistics. Pairing is accomplished by randomly selecting products from a product class. For each selection, the most similar product from the other class is selected to form a pair.

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to a real product. Two methods resolve this dilemma. First, the product could be the object of a combinatorial optimization function (e.g., proteins or integrated circuits). Second, one can use abstract products (e.g., a string of letters). Because students will have difficulty ‘feeling’ that they are managing a business when the product is abstract, one gives abstract products a visual representation, such as plants, flowers, or faces.

CONSEQUENCES OF THE NEW METHOD

Innovation

With the new method, students no longer purchase samples from probability distributions. They design products by assembling characteristics. Through market analysis, students identify characteristics that contribute significantly to products’ values and combine these characteristics to create high value products. Because students design products, innovation is defined in terms of product design. Specifically, an innovation is a product that differs from the previous products offered to the marketplace by at least one characteristic.

Defining One’s Business with Product Classes

When designing products, students face two problems:

First, there are an enormous number of designs. Suppose, for example, that twenty attributes comprise products and that each attribute expresses one of twenty-five characteristics. Students can choose from 25^{20} unique products. A student can consider only a small number of these possibilities. He must find an efficient means reducing this set of choices to a smaller, manageable set of high value products.

Second, attributes interact and produce frustration. Because of this, students cannot optimize design by considering each attribute

independently. Instead, each student must discover valued combinations of characteristics. How can a student efficiently search for high value products? A student does this by hypothesizing product classes. By searching product classes, a student greatly simplifies his design problem. He can evaluate the potential of an entire class of products rather than evaluate every single product. He does this by evaluating a few products from a product class and, using this information, estimating the product class’s potential. A firm’s budget will not permit exploring all of the product classes that a student deems potentially valuable. This combination of estimates and a limited budget makes success a matter of probability. Selecting product classes to search is a risky decision. It is also an important decision. The product classes that a student focuses upon define his business.

In each product class, the products produce a unique distribution of product values. This distribution is analogous to the probability distributions with which the previous method simulates innovation. There is one momentous difference. The previous method defines the probability distributions exogenously. They are ‘givens’. In the new model, the student defines product classes. The student determines whether he searches a barren class or one pregnant with innovations. Moreover, a student changes the product classes that he searches as he gains knowledge. His hypothesized product classes are a function of his development and application of knowledge.

Market Analysis and Defining Markets

To design products and hypothesize and evaluate product classes, students analyze the marketplace results (which products sold and at what prices). They search for valued combinations of characteristics. These combinations produce fertile product classes from which to search for innovations. If a student desires more information (a combination of characteristics has

not appeared in a sufficient number of products), the student will experiment by manufacturing a small quantity of products and offering them to the marketplace.

A forbidding problem confronts students' analysis of the marketplace results. The marketplace produces an enormous amount of information. If n attributes comprise products, the marketplace's evaluation of a single product provides information about the value of 2^n product classes.³ No person can consider all of this information.

To cope with the voluminous information, students must select the information that is most effective and relevant to their businesses. They accomplish this by focusing on a few product classes. This has the effect of classifying the marketplace data. I call a set of product classes used for this purpose a *perspective*. A perspective constitutes a student's definition of the market. Is it a market for sports cars or limousines?

A perspective filters marketplace information. It is a student's means of 'framing' the complex problem of competing, surviving, and profiting. Different perspectives filter the marketplace results differently. Students with different perspectives will identify and miss different opportunities; evaluate product classes differently; and value information differently. Results that are surprising to one student might easily be anticipated by a student with a different perspective.

³ A product presents a group of n characteristics to the marketplace. The number of combinations of characteristics evaluated by the marketplace is the number of sets that one can create from n objects. This number is 2^n .

Core Competencies

Suppose a student develops knowledge of a product class that enables efficient innovation within this class. The product class constitutes a *core competency* of the student. A student's core competencies can be recorded through statistical measures (measures of central tendency and variation) of the products, and their values, that the student offers the marketplace. By applying such measures over successive rounds, one can illustrate the path-dependent nature of innovation. If desired, one can also apply these measures to the output of a group of firms.

Short- and Long-Run Strategies

Using perspectives and product classes to search for high value products creates a dilemma for students. A student can direct his efforts and investment towards product classes that the marketplace results have identified as most promising (classes that have done well in previous rounds). By exploiting this 'current' knowledge, a student immediately increases his firm's profits and the competitive pressure on his competitors. This is a short-run strategy.

Alternatively, a student can focus his efforts and investment on discovering new, superior product classes (developing new core competencies). By developing new knowledge, a student can gain a large competitive advantage in future rounds. This requires time and investment. It also incurs the risk that no superior product classes will be found. Searching for superior product classes is a long-run strategy. Balancing investment between these two alternatives, short-run and long-run, is the quintessential knowledge management dilemma.

A Continuum of Innovations: Incremental through Radical

Through the correlation of product classes, the model permits defining a measurable continuum

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of innovation types. Consider the product classes containing a significant number of the products offered to the marketplace in previous rounds. Incremental innovations are innovations from product classes that are highly correlated with at least one of these product classes. Radical innovations are innovations contained in product classes that are not correlated with these product classes. Innovation type is measured by these correlations, on a scale of zero to one.

It is important to note that every product is a member of many product classes (2^n as described above). Whether a student sees an innovation as incremental or radical, or to what degree in between, depends upon the student's perspective as well as on the new product. A student with a good perspective will be able to reduce the risks and costs of innovation.

Technological Advance

Intuitively, technology limits one's capability of designing and producing products. Within technological limits, design and production are possible. Outside technological limits, they are not. Consistent with this intuition, the new method simulates technological advance with the following process: At the start of a learning session, many product characteristics are not allowed in product designs. These characteristics are 'off-limits'. Students design products within these bounds, and their knowledge develops from exploring this limited set of products. During the simulation, the restrictions are relaxed, simulating technological advance. Multitudes of new products and product classes become available.

After a technological advance, students compete by exploiting the new opportunities. They must discover new, profitable product classes and products. This requires developing new core competencies while shedding the knowledge made obsolete by the technological advance. In the process, students will have to develop new

definitions of the market (new perspectives) and new definitions of their firms' businesses (new product classes). In extreme cases, students will have to 'reinvent' their firms.

Royalties

By 'patenting' new products and granting royalties, the simulation controls the appropriability of innovation. A patent on a product covers itself and all products that differ by less than a predetermined number of characteristics. The scope of patents, the magnitude of the royalties, and the duration of patents are parameters set at the start of a simulation.

ADAPTIONS OF THE MODEL

Modeling Exogenous Market Disturbances

One can include exogenous market disturbances by letting a portion of the attributes represent exogenous factors. Students do not view these attributes. By intermittently changing the characteristics expressed by these attributes, one simulates exogenous shocks to the marketplace. Students must adjust their product designs and business strategies in response to these shocks.

Modeling Product Applications

A portion of the attributes can describe products while another portion describes customers' applications of a product (call these attributes, application attributes). Interactions between product attributes and application attributes represent the effect of product changes on the applications and of using existing products in new applications. Several variations arise from this formulation. First, customer groups seeking products for different applications provide a means of representing distinct market segments. Second, the simulation can intermittently change the characteristics expressed by the application attributes. Students must adapt their firm's

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products to these changes. Changes can vary in 'size' from incremental to radical. Third, students can search for both new products and new product applications. Students will manage both product research and market development.

Teaching Teamwork

By having a team of students control a firm, the model can teach coordination and teamwork. Some students set 'corporate' strategy (designing the general characteristics and requirements of a firm's portfolio) while other students design products. To teach the importance of information and communication, one can limit the communication between the two groups. In another exercise, one can let several students control a firm and divide a product's attributes into several groups (for example, attributes one through five, six through ten, and eleven through fifteen, etc.). Each student designs one segment. Interactions between attributes represent the impact of one student's decisions on other students' designs. To design high value products, students must coordinate their efforts and work as a team.

CONCLUSION

Though appropriate for teaching other business functions, previous methods of modeling innovation are not suitable for teaching the management of innovation. The method presented herein – where students use marketplace data to find solutions to a combinatorial optimization problem – is suitable for this purpose. It reproduces the essential properties of innovation, including unpredictability, surprise, path-dependency, and probabilistic success. It requires that students design products, hypothesize perspectives, and manage their firms' long-run and short-run strategies. It also simulates technological advance and provides means for measuring innovation and students' core competencies.

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