MODELING NON-PRICE FACTORS IN THE DEMAND FUNCTIONS OF COMPUTERIZED BUSINESS SIMULATIONS

Steven C. Gold, Rochester Institute of Technology
Thomas F. Pray, Rochester Institute of Technology

ABSTRACT

This paper evaluates the way in which non-price factors of demand are modeled in computerized business simulations. It is found that several different functional forms are utilized. The properties of these functions are reviewed and compared to modern demand theory. A recommended functional form for modeling demand is then presented and illustrated with a numerical example.

INTRODUCTION

Non-price factors of demand, like advertising and promotion, are fundamental components of most computerized business simulations. Students by making these types of decisions in a simulation environment, are supposed to gain insights into business theories or concepts. Accordingly, it is necessary for the mathematical functions or algorithms embodied in the simulations to reflect the relationships described by business or economic theory.

At the 1981 ABSEL conference a paper presented by Kenneth R. Goosen[6} emphasized the need to expand the research concerning the internal design or modeling of computerized business simulations. He noted that the current and past papers presented at ABSEL do not provide enough information to help designers develop simulations in an efficient and effective manner and concluded:

The designing and developing of simulations... appears to be primarily an art form, a creative skill based on intuitive feel rather than acquired knowledge.

This raises a number of interesting questions. How are non-price factors modeled in business simulations? Do the simulation functions have the properties described by conventional demand theory? What are the advantages and disadvantages of alternative modeling approaches? An understanding of these issues should enhance the development and effectiveness of future simulations.

PURPOSE

The purpose of this paper is fivefold:

(1) to examine the different ways in which computerized business simulations have modeled non-price factors of demand;

(2) to review the theory of demand, focusing on non- price factors and the characteristics of inflection points;

(3) to specify a flexible and stable functional form that is consistent with the properties of modern demand theory;

(4) to derive mathematical expressions for the elasticity and inflection point of the demand function; (5) to illustrate with a numerical example the procedure involved in determining the parameter values of the demand function after specifying the elasticity and inflection point.

THE DATA: SELECTED SIMULATIONS

Five commercially available business simulations of different vintages (publication dates) were selected for review and analysis. The selection was based on three criteria: (1) the utilization of a demand function; (2) the inclusion of non-price factors in the demand function; and (3) a published source listing of the computer software program.

A list of the selected simulations is reported in Table

1. The vintages range from 1968 to 1983. This wide range provides a historical perspective of demand modeling. The complexity of the simulations is compared by measuring three factors: the number of decision variables, the number of products, and the maximum number of firms in the market. Based on this criteria, the least complex simulations were the earlier vintages, i.e. Integrated simulation and the Executive Game. The most complex simulation appears to be the Multinational Game with 18 decision variables and two market products.

TABLE 1
CHARACTERISTICS OF SELECTED SIMULATIONS

Title	Vintage (Publication Date)	Decisions	Number of Products	Number of Firms (Max.)
Integrated Simulation	1968	8	1	9
Executive Game	1972	8	1	9
Multinational Game	1980	18	2	9
DECIDE	1981	13	1	9
MICROSIM	1983	8	1	99

REVIEW OF SIMULATION DEMAND FUNCTIONS

The selected simulations use a variety of different independent variables and functional forms. The precise firm level demand functions embodied in each simulation are reported in Table 2 with a list of variable definitions.

Two simulations used non-linear functional forms:

Integrated and the Multinational Game - Product A. All the remaining simulations used a common functional form referred to as log - linear. A paper by Pray and Gold[8] evaluated the advantages and disadvantages of these types of functions and concluded:

(1) the non-linear demand functions permit variable elasticities, however, they tend to be "highly unstable and constraints on decision variables are needed.” (Constraints were placed on the simulations using this functional form.)

TABLE 2
FIRM DEMAND FUNCTIONS IN SELECTED SIMULATIONS

Simulation	
Integrated	$d = (\frac{110M+90R+10000}{2P-50} + 2\ M+R-AM-AR + (AP-P))E$
Executive	$w = (10-P)^{2.8}\ ((M+50000)(R+20000))^{0.7}$
Multinational- Product A	$w = (\frac{100}{n} + 5F+3G+7\bar{M}+5\bar{R}+5cP)/(P/AP)^{1.8}$
Product B	$w = (AP/P)^{3}\ (R/AR)^{1}$
DECIDE	$w = (AP/P)^{8}\ (M/AM)^{1.53}\ (R/AR)^{1.02}$
MICROSIM	$w = (AP/P)^{(2+N/3)}(M/AM)^{0.6}\ )R/AR)^{0.5}$

Definitions of Variables:

A = an "A" before any symbol refers to the average value, e.g. AM refers to the average of M (marketing).

c = percent commission on sales.

d = firm quantity demanded.

E = economic index.

F = distribution centers - average number of centers.

G = salesmen - average number of salesmen.

M = marketing, advertising, or promotion.

$\bar{M} = (\frac{M}{AM} - 1)/1.8.$

N = number of firms or teams.

P = price of product.

R = research and development or productquality.

$\bar{R} = -(\frac{AR}{R} - 1)^{.5}/1.8$ if $(R-AR)<0$; $\bar{R} = (\frac{R}{AR} - 1)^{5.}/1.8$ if $(R-AR)>0$

w = weight factor used in determining the firm's market share and demand. A firm's market share is its own weigh, w, divided by the sum of all the firm weights in the industry or market.

(2) the log-linear demand functions constrain the elasticities to be constant, but the functions are stable. However, "at the firm level care must be taken to avoid zero level decision variables."

The primary focus in this study pertains to the way in which the marketing (M) and research and development (R) are modeled in the demand functions. Are the properties of the demand functions consistent with the propositions described in modern demand theory? Table 3 provides information on the non-price elasticities implied by the functional forms used in each of the simulations.

TABLE 3
FIRM LEVEL NON-PRICE ELASTICITIES

Simulation	Marketing	Research & Development
Integrated	0.75	0.75
Executive	0.70	0.70
Multinational-		
Product A	1.00	0.50
Product B	none	1.00
DECIDE	1.50	1.02
MICROSIM	0.60	0.50

Non-price elasticities measure the percentage change in the quantity demanded due to a percentage change in the non-price variable (in this case marketing or R & D). An elasticity less than 1 indicates diminishing returns to the non-price factor. An elasticity greater than 1 implies increasing returns to the non-price factor. Referring to Table 3, diminishing returns to marketing occurs in three of the five simulations. Only one simulation has increasing returns - DECIDE. The Multinational Game has constant returns to marketing expenditures for Product A, and constant returns to R & D expenditures for Product B.

DEMAND THEORY: NON-PRICE FACTORS

In theory, demand is a function of price, as well as a vector of non-price factors which includes: the prices of related goods, income, marketing, and product quality (R & D).

$$Q=f(P, P_S, P_C, Y, M, R)$$

where: P price of product
P_S = price of substitute good
P_C = price of complement good
Y = income
M = marketing
R = research & development (quality measure)

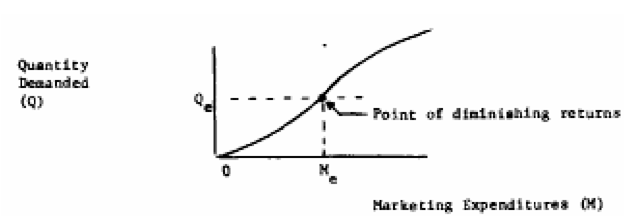
Apriori expectations as to the sign of the relationship between demand and the independent variables for a normal good are as follows:

$dQ/dP<0$; $dQ/dP_S>0$
$dQ/dP_C<0$; $dQ/dY>0$
$dQ/dM>0$; $dQ/dR>0$

Since the focus of this study pertains to the non-price factors of marketing and R & D, the second order conditions for the variables are specified below:

$d^2Q/dM^2>0$; $d^2Q/dR^2>0$ (increasing returns)
$d^2Q/dN^2=0$; $d^2Q/dR^2=0$ (constant returns)
$d^2Q/dM^2<0$ $d^2Q/dR^2>0$ (decreasing returns) This relationship for the marketing variable is illustrated graphically in Figure 1.

FIGURE 1
RELATIONSHIP BETWEEN MARKETING AND DEMAND



Increasing returns to marketing occur for expenditure levels between 0 and M_e, i.e. the slope of the function rises. Expenditure level M_e (point E)is the inflection point of the function or commonly referred to as the point of diminishing returns. After point E, additional expenditures on marketing realize decreasing returns, i.e. the slope of the function declines.

COMPARISON OF SIMULATION DESIGN WITH DEMAND THEORY

The demand functions embodied in the simulations (previously reviewed) did not possess the inflection point characterized by modern demand theory. The DECIDE simulation had increasing returns over all ranges of marketing and/or R & D expenditures. The Multinational Game had constant returns over all ranges of marketing (product A) and R & D (product B) expenditures. The remaining simulations possessed decreasing returns over all ranges of expenditure.

The functional forms adopted in these simulations were not flexible enough to permit the modeling of an inflection point. The remainder of this paper presents and evaluates a more flexible functional form.

A SUGGESTED DEMAND FUNCTION

A functional form recommended for modeling demand in computerized business simulations was presented in a 1983 paper by Gold and Pray[5]. This function is given below:

$$Q = a_o\, p^{-(a_1 + a_2 P)}\, M^{+(a_3 - a_4 M)}\, R^{+(a_5 - a_6 R)} \qquad (1)$$

where: Q = quantity
P = price
M = marketing
R = R & D
a_i = parameter i

The functional form is multiplicative but is not log- linear. The authors have shown this function to be stable while possessing the fundamental characteristics of demand theory.

DERIVING THE INFLECTION POINT

The inflection point (or point of diminishing returns) for the marketing variable will be derived. The derivation is general and holds for all non-price variables in this particular function.

Using partial analysis (i.e. holding P and R constant) the demand function is reduced to:

$$Q = kM^{(a_3 - a_4 M)} \qquad (2)$$

where k = a constant (containing P and R)

Taking the natural log of equation (2):

$$\ln Q = \ln k + (a_3 - a_4 M) \ln M \qquad (3)$$

The derivative of the function yields:

$$dQ/Q = (a_3 - a_4 M)dM/M - a_4 \ln M dM \qquad (4)$$

where: dQ, dM are <u>partial</u> derivatives

Solving for the marketing elasticity (e) and simplifying

$$e = a_3 - a_4 M(1 + \ln M) \qquad (5)$$

where: e = (dQ/dM)(M/Q) elasticity

The marginal impact of marketing (dQ/dM) may also be expressed from equation (4):

$$dQ/dM = (a_3 - a_4 M(1+1nM))(Q/M) \qquad (6)$$

At the inflection point the second derivative of Q with respect to M is zero:

$$d^2Q/dM2 = 0 \qquad (7)$$

Solving equation(7) by taking the derivative of equation (6) with respect to M and setting it equal to zero, yields:

$$e^2 = a_3 + a_4 M \qquad (8)$$

where: e = elasticity for marketing

$$e2= (a_3 - a_4 M(l+\ln M))^2$$

Consequently, the inflection point is characterized by equation (8), that is, the marketing elasticity squared equals the sum $a_3 + a_4 M$ at the inflection point.

SOLVING THE PARAMETER VALUES: AN EXAMPLE

An example of how to determine the parameter values of the demand functions after specifying the characteristics of the inflection point is presented to demonstrate the properties of the functional form and the ease in which the parameter values are solved.

The simulation designer need only specify the level of marketing expenditures and the elasticity at the inflection point. Assume the following specification:

oMarketing expenditures of $100,000

oMarketing elasticity of 2.0

Substituting the values for marketing expenditures and elasticity into equations (5) and (8) yield, respectively:

$$2.0 = a_3 - a_4 100{,}000(1+1n100{,}000);\ \text{from equation (5)} \qquad (9)$$

$$4.0 = a_3 + a4100{,}000;\ \text{from equation(8)} \qquad (10)$$

Solving equations (9) and (10) simultaneously, the values for a_3 and a_4 are:

a = 3.65256

$a = 1.48007 \times 10^{-6}$

Substituting the value of the parameters into equation (2) gives:

$$Q = kM^{3.65256-0.00000148M} \qquad (11)$$

The parameter "k" is simply a scaling factor and may be arbitrarily assigned a value. (In this case the demand variables other than marketing are assumed to be held constant.)

The relationship between marketing and demand portrayed by equation (11) is illustrated numerically in Table 4. (A value of k of 3.0008x10 was assumed.) The marginal impact of marketing is the change in quantity demanded divided by the change in marketing expenditures. Note that the marginal impact of marketing increased from 150 units per dollar to 182 units per dollar as marketing rises from $60,000 to $100,000. After marketing expenditures of $100,000 the marginal impact declines, indicating diminishing returns. The inflection point occurs, therefore, at the $100,000 level as initially specified by the simulation designer in the hypothetical example. Note that the shape of this function corresponds to the illustration in Figure 1.

TABLE 4
THE MARGINAL IMPACT OF MARKETING EXPENDITURES

Marketing Expenditures	Quantity Demanded (units)	Marginal Marketing Impact (units/$)
60,000	3,201,854	xxx
70,000	4,701,894	150
80,000	6,405,536	170
90,000	8,184,052	178
100,000	10,000,000	182
110,000	11,789,374	179
120,000	13,401,302	161
130,000	14,903,767	149

SUMMARY AND CONCLUSION

The modeling of demand is an important component of most business simulations. The simulation designer, therefore, should be careful in selecting the functional form for demand. A review of several past simulations indicate a number of different functions were selected. However, none of these functions were flexible enough to embody the standard inflection point characterized by demand theory. A demand function which overcomes this problem was presented and evaluated. This function is flexible enough to possess the properties described by demand theory but is simple enough to be easily solved for the parameter values.

The paper’s intent is not to criticize the sample simulations. The purpose is to encourage more open discussion pertaining to the modeling of simulations. This type of research and dialogue should enhance the effectiveness of simulations in the classroom and, perhaps, the future of experiential, learning via the computer.

REFERENCES

[1] Brooks, LeRoy D., Instructors Manual - The Financial Management Decision Game, (Richard D. Irwin, Inc., Homewood, ILL.), 1975.

[2] Darden, William R., William H. Lucas, The Decision Making Game-An Integrated Operations Management Simulation, (Appleton-Century Crofts, New York), 1969.

[3] Edge, Alfred G., Bernard Keys, William E. Reymus, Instructor’s Manual The Multinational Management Game, (Business Publications Inc., Dallas), 1980.

[4] Gold, Steven C., Thomas F. Pray, Terry Dennis, MICROSIM - A Microeconomics Simulation, (MacMillan Publishing Co. copyright 1983).

[5] Gold, Steven C. and Thomas F. Pray, “Simulation Market and Firm Level Demand - A Robust Demand System,” Developments in Business Simulation And Experiential Exercises, Vol. 10, 1983, pp. 101-106.

[6] Goosen, K., “A Generalized Algorithm For Designing And Developing Business Simulations,” Developments In Business Simulation and Experiential Exercises, Vol. 8, 1981.

[7] Henshaw, Richard C., James R. Jackson, The Executive Game, Rev. Ed., (Richard D. Irwin Inc., Homewood, ILL.), 1972.

[8] Pray, T. and S. Gold, “Inside The Black Box – An Analysis of Underlying Demand Functions in Contemporary Business Simulations.” Developments In Business Simulation and Experiential Exercises, Vol. 9, 1982. pp. 110-115.

[9] Pray, Thomas F.., Daniel R. Strang, Instructor’s Manual for DECIDE, (Random House, Inc., New York) 1981.

[10] Smith W. Nye, Elmer Estey, Ellsworth Vines, Integrated Simulation (South-Western Publishing Co., Cincinnati) 1974.