INSIDE THE BLACK BOX: AN ANALYSIS OF UNDERLYING DEMAND FUNCTIONS IN CONTEMPORARY BUSINESS SIMULATIONS

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ABSTRACT

The paper reviews and compares the specific ways that eight(8) business simulations modeled their demand functions. It discusses the theoretical and empirical properties that should be embodied in both market and firm demand functions. The actual demand functions are then compared to the theoretical propositions contained in modern demand theory. The paper concludes by evaluating the advantages and disadvantages of utilizing different approaches and functions for modeling demand. It was found that the simulations studied contained many different demand forms. Certain functions or approaches performed well over the apriori defined demand criteria, while others were somewhat unstable and yielded unrealistic results. The paper's intent is not to criticize or compliment the sampled simulations, but rather to discuss a modeling approach based upon theory that should be used for effective modeling of demand.

INTRODUCTION

In a paper presented at the 1981 ABSEL conference entitled, “A Generalized Algorithm For Designing and Developing Business Simulations, Kenneth R. Goosen noted that in past ABSEL conferences approximately sixteen professional papers have dealt with design concerns in creating a simulation. However, he argued that:

> “…taken collectively these papers do not provide enough information to help the novice designer develop simulations in an efficient manner. The designing and developing of simulations. . .appears to be primarily an art form, a creative skill based on intuitive feel rather than acquired knowledge.

Professor Goosen’s paper presented some important and key principles which would assist the novice in the flowcharting and macro’ design aspects of simulation construction. There is, nevertheless, a paucity of material concerning the ‘micro” (internal) components within a simulation. Critical design issues such as: “How are production processes modeled? How does one mathematically specify the market demand?, or What is the best manner of introducing uncertainty? are left unexplained. Users of the simulation are sometimes puzzled about the results of a teams play. Questions such as” Why was there such stability in price? or Why was there such an enormous increase in marketing or R&D expenditures over the semester's play? These questions, both from designers and from a users point of view are not adequately reviewed in the literature. There appears to be a reluctance, even by ABSEL members, to discuss internal modeling components. <u>The secrecies of the internal workings of the simulations’ black box have been well preserved</u>. However, the specification and construction of the mathematical functions and algorithms necessary to generate the decision values are crucial components of any business or management simulation.

Business and management simulations in particular are modeled to represent real world firm and market environments. Students are supposed to gain insights into the workings of the real world by participating in a simulation. As a result it is necessary for the functions and algorithms within the simulation to reflect, or at least be consistent with, the economic, managerial and financial relationships found in the real world. Although these underlying principles or theories explaining real world phenomenon are well-known, the task of precisely modeling and quantifying these relationships in a simulation are not straight forward. Understanding the pros and cons” of different functional forms can vastly facilitate the modeling process. A proper appreciation by designers and users of the different modeling approaches can also prevent the games from yielding unreasonable results (i.e. blow up). It is, however, <u>unfortunate</u>, that very little has been written or presented on the modeling of these internal functions.

PURPOSE

The purpose of this paper is fourfold: (i) to review and compare the specific ways in which business (computerized) simulations have modeled <u>demand functions</u>. This is accomplished by going inside the simulation black box and examining the underlying demand functions utilized in a number of contemporary business simulations covering the major functional areas of business; (ii) discuss the theoretical and empirical properties that should be embodied in both market and individual firm demand functions. Fundamental concepts such as the law of demand, diminishing returns, elasticity variability, parameter flexibility, functional form selection, general sensitivity, and intertemporal analysis are reviewed and rank ordered. The selected simulations are compared vis-à-vis the properties of demand; (iii) propose a direction for the effective design and modeling of the micro aspects of demand functions; and (iv) encourage present and future simulation designers to be more open about the internal workings of their simulation black box. Ideally, an ongoing discussion by ABSEL members could improve not only the modeling of demand components, but also enhance open communication about other internal components of simulation design. This may in turn stimulate the growth and development of new simulations by facilitating the novice designer.

METHODOLOGY AND DATA

The methodology employed in the analysis involved two phases. In phase I, a number of ongoing computerized simulations covering the major functional areas of business were selected and analyzed. Both unpublished and commercially available simulations were investigated on the basis of (i) coverage of at least one primary functional area of business and (ii) whether or not they utilized a market demand concept. In the final analysis, eight(8) simulations were chosen and serve as the basis for the paper. These simulations comprise a wide range within the functional areas of business. Table 1 summarizes the simulations reviewed, including information on: date of publication, major area of emphasis, complexity of the game (proxied by the number of decision variables) and number of products. Furthermore, the table provides information concerning whether or not the game was competitive (interactive) in nature, the type of market structure and the firm evaluation or ranking criteria.

As noted in Table 1, three general business/management simulations were reviewed. Each are similar in content and complexity, but vary in their historical place in the relatively short history of simulation gaming. Two production/operations management simulations were selected. OPSIM was an early vintage production oriented simulation which had a relatively short publication life, and is no longer commercially available. The other, PRODUCE, is a complex graduate level operations management game, which is unpublished.[1] This simulation while complete is still in the testing stages. A financial management game, which is non-interactive in nature but employing an underlying demand function, was selected. One recently published multiproduct international game was analyzed because of its unique underlying firm and industry demand functions. The last simulation reported is a new unpublished game which allows the students to study micro- economic theory for all four market structures.

While these simulations do not cover all functional areas within business, they represent a broad range of simulation activities not only in function, but also in regard to complexity and historical development.

In managerial economics, the mathematical forms of the function are often described. Two common forms are outlined below:

(1) $Q = a + bP + cA + dY + ePr$

(2) $Q = a + p^b A^c Y^d Pr^e$

Equation (1), the linear model, is often employed in econometric analysis primarily because (i) experience indicates many demand relationships are approximately linear over the range of data; (ii) convenience in estimation, via least squares and (iii) the impact on demand of a marginal change in any demand variable is independent of the other demand variables.

Equation (2) the power function is probably the second most popular econometric functional form. It has gained its popularity for the following reasons (1) it too, is easily estimated via log-linear regression techniques; (ii) gives good econometric results (i.e. goodness of fit, etc.) and (iii) the impact on demand due to a marginal change of say advertising, a variable,

$$\left(\text{e.g. } \frac{\partial Q}{\partial A} = ca\ P^D A^{c-1} Y^D Pr^e\right)$$

TABLE I

Summary of Games Analyzed

	PUBLICATION DATE	MAJOR EMPHASIS FUNCTIONAL AREA	MARKET STRUCTURE	NO. OF MARKETS	NO. OF PRODUCTS	NO. OF DECISIONS	INTERACTIVE YES OR NO	MAX. NO. OF TEAMS	TEAM RANKING SUCCESS MEASURES
Integrative Simulation	1968	GB/MGT	olig.	1	1	8	Yes	9	STKMK
Executive Game	1972	GB/MGT	olig.	1	1	8	Yes	9	STKMK
Decide	1981	GB/MGT	Olig.	1	1	13	Yes	9	STKMK
OPSIM	1969	Prod/ Operation	Olig.	1	2	13	Yes No	9	Contrib. Profit
Produce	1982*	Prod/ Operation	Olig.	1	2	50	Yes	9	Multi-Criteria
Financial Mgt. Game	1975	Fin/Mgt. Econ.	—	1	1	18	No	99	Stock Holder Wealth
Multinational	1980	Int. Mgt.	Olig.	3	2	18 per Mkt.	Yes	9	Multi - criteria
Microsim	1982*	Micro Econ	All	1	1	8	Yes	99	Profit

*unpublished

is not constant but rather depends on its value, as well as, other independent variables. This changing marginal relationship is often said to be more realistic than the constant, implicitly assumed in the linear model.

Both models have their advantages and disadvantages. The linear model permits a wide range of elasticities for the independent variables, while the multiplicative form restricts elasticities to be a constant (i.e. the power is the elasticity).

DEMAND THEORY-REVIEWED

Economics texts purport that demand is a function of a number independent variables such as price, income, price of related goods, advertising, etc. They go on to elaborate on the apriori expectation as to sign of the relationship between the demand and the independent variable. For normal goods, as an example, the relationship may well appear as follows:

$$Q_X = f(-P_X, +A, +I, -P_R)$$

where
- P = Price of X
- A = Advertising expenditure
- I = Income level
- P_R = is price of a substitute item

THE SIMULATIONS - DEMAND INPUTS AND MODELING CHARACTERISTICS

The eight simulations reviewed used a variety of different independent variables (inputs in the decision making process) and embodied the inputs in a number of different functional forms. Some simulations were non- competitive or non-interactive and thus the entire demand function modeled was applied to the individual fire. Other simulations maintained a market or industry

[1] It is, however, under contract with Random House Publishing Company

demand concept and then distributed the "pie~ to the individual firms. The latter case implies two demand functions. The first an industrial (I) demand curve and the second a firm (F) demand curve. As noted in Table 2 the firm demand curves typically involve individual values of price, promotion and development as well as average values. Most interactive simulations embodied the number of firms and some economic indexes to regulate the lever of demand. A few incorporated variables such as time, returning stockouts, price of related goods, as well as some relatively unique factors like number of salesman, number of distribution centers, and commission rates.

TABLE 2

Demand Inputs

Game	PRICE	AVG. PRICE	MARKETING	AVG. MARKETING	R&D/QUAL	AV. R&D	NUMBER OF FIRMS	INDEXES OF ECONOMY	TIME	STOCKOUTS	PRICE OF RELATED GOODS	OTHER
INTEG. (F)	✓	✓	✓	✓	✓	✓		✓				
EXEC. (I)		✓		✓		✓	✓	✓				
EXEC. (F)	✓		✓		✓					✓		
DECID (I)		✓		✓		✓	✓	✓	✓	✓		
DECID (F)	✓	✓	✓	✓	✓	✓						
PRODU (I)		✓					✓	✓		✓	✓	
PRODU (F)	✓	✓										
OPSIM (F)	✓	✓						✓	✓	✓		
FIN. MGT. (F)	✓							✓				✓
MULT. (I)		✓		✓		✓	✓	✓				✓
MULT (F)	✓	✓	✓	✓	✓	✓						✓
MICRO (I)		✓		✓		✓	✓			✓	✓	✓
MICRO (F)	✓	✓	✓	✓	✓	✓						

(I) indicates industry level

(F) indicates firm level

Table 3 summarizes in a non-technical fashion ~ number of modeling characteristics. Generally, modeling of the market or industry demand curve was performed using three(3) types of mathematical functions: linear functions, power or log linear functions, and some intrinsically non-linear functions. The actual functional form is presented in Appendix A. As noted approximately fifty percent of the simulations investigated incorporated uncertainty in the demand function. This uncertainty was introduced externally, either via discrete probability functions vis-à-vis random number generations or through instructor modification of control cards. The majority of the simulations had art inter- temporal component within the demand analysis. This was done with the use of single exponential smoothing. As might be expected apriori, larger smoothing coefficients were placed on price and promotional (marketing) variables than on quality or research type variables.

The last column of Table 3 indicates that four simulations imposed restrictions on decision inputs. These restrictions were more than the obvious constraints such as not permitting 'negative' prices or values. The need for these restrictions become clear when the price elasticity of demand is examined.

PRICE ELASTICITY OF DEMAND

The price elasticity measures the sensitivity or responsiveness of quantity demanded to changes in price and is one of the key components of the demand function. Economic theory provides some general guidelines concerning the relationship between price and quantity

TABLE 3

Demand Modeling Characteristics

	Functional Form	External Uncertainty in Demand	Intertemporal Demand Strategies	Restrictions on Demand Inputs
Integ (F)	Non Linear	None	None	Max ± 20% Per Quarter (1)
Exec (I)	Log Linear	None	Yes	None
Exec (F)	Log Linear	None	None	Max Price = 9.00 (2) Min Price = 3.00
Decid (I)	Log Linear	In returning Stockout - Ran**	Yes	None
Decid (F)	Log Linear	None	Yes	None
Opsim	Linear	Trend Demand Stockouts - Ran**	None	None
Produ (I)	Log Linear	Returning Stockouts - Ran**	Yes	None
Produ (F)	Log Linear	None	Yes	None
Fin. Mgt. (F)	Linear	To add fluctuation - Ran**	None	None
Multi (I)	[illegible]*	None	Yes	Price restriction (3)
Multi (F)	[illegible]*	None	Yes	Price≥cost and max price = $75 (4)
Micro (I)	Log Linear	None	Yes	None
Micro (F)	Log Linear	None	Yes	Excessive stockouts reallocated to other firms (5)

* one product was non-linear, the other log linear

** Ran implies use of random numbers to simulate a probability function

(1) The promotion and quality variables are restricted to a maximum of 20% changes per period, with a lower limit of 50% overall. The price variable is restricted to a 10% change per period with a minimum of 50%

(2) The price constraints are totally imposed by the algorithm

(3) If the firm's price is more than ± $10 from the average, the price is removed from the average calculation

(4) Price must be equal to unit cost, otherwise it is set at the unit cost level. For one of the products, if the Average Price exceeds fifty dollars, the demand is forced to zero. In U.S. dollars, the maximum price cannot exceed 75 dollars

(5) If a firm has an extremely low price, capturing an inordinate share of the market, but fails to have adequate finished goods, the subsequent stockouts are reallocated to other firms

demanded, but the precise empirical relationship is not well defined, the magnitude of the price elasticity depends on: (i) the type of good-necessity or luxury, and (ii) the type of market-competitive or noncompetitive. Nevertheless, simulation designers must make decisions concerning the magnitudes of the price elasticity relationships; and simulation users, in most cases, must accept the relationships embodied in the chosen game. This section examines: (1) the range of price elasticities in the selected simulations, and (2) ascertains whether or not the price elasticities are reasonable and consistent with economic theory.

Table 4 presents the values of the price elasticities of demand on both the industry and firm levels for the selected simulations.[2] For purposes of comparison,

[2] The point price elasticity of demand was calculated by using the conventional formula: elasticity = (dq/dp) (p/q) where p = price and q = quantity. Values for the other variables in the demand function were set equal to the starting of base values for the particular simulations.

TABLE 4

Price Elasticity of Demand At Different Price Levels

Simulation	Level of Demand	Standardized Price Level* 25	50	100	150	200
Integrated	Firm	∞	-1.90	-1.82	-4.18	+21.08
Executive	Ind.	-0.32	-0.75	-2.20	-9.00	+24.00
Executive	Firm	-0.49	-1.20	-4.00	-25.20	-16.80
Decide	Ind.	-0.90	-0.90	-0.90	- 0.90	- 0.90
Decide	Firm	-8.00	-8.00	-8.00	- 8.00	- 8.00
OPSIM-Prod. 1	Firm	-0.20	-0.48	-1.87	-44.18	+ 4.29
OPSIM-Prod. 2	Firm	-0.21	-0.53	-2.25	+27.21	+ 3.60
PROD.-Prod. 1	Ind.	-0.45	-1.11	-2.64	- 4.34	- 6.15
PROD.-Prod. 2	Ind.	-0.35	-0.50	-0.86	- 1.26	- 1.70
PROD.-Prod. 1	Firm	-1.00	-1.00	-1.00	- 1.00	- 1.00
PROD.-Prod. 2	Firm	-1.00	-1.00	-1.00	- 1.00	- 1.00
Finance	Firm	-0.14	-0.33	-1.00	- 3.00	+ ∞
Multinational						
-Prod. A	Ind.	-0.65	-0.79	-0.88	- 0.92	- 0.94
-Prod. B	Ind.	-0.21	-0.49	-1.59	- 6.13	+14.30
-Prod. A	Firm	-1.45	-1.28	-1.11	- 1.03	- 0.99
-Prod. B	Firm	-3.00	-3.00	-3.00	- 3.00	- 3.00
Microsim	Ind.	-0.52	-0.55	-0.63	- 0.72	- 0.82
	Firm	-6.00	-6.00	-6.00	- 6.00	- 6.00

* Standardized Price = (Firm Price/Base Price Level) X 100, where the Base Price Level is the starting value for price or the price used for illustrative purposes in the Simulation Manual

prices are standardized by setting the starting price level (or the prices used for illustrative purposes) in each simulation equal to 100. As a consequence, a 50% increase in price from initial levels would be represented by an increase in standardized prices from 100 to 150 independent of the base price used in the particular simulation.

Several interesting observations may be drawn from the Table. At the start of each simulation (where standardized price is equal to 100), the price elasticity of demand on the firm level is greater than or equal to one (in absolute terms) in all markets. The range is from a low of 1.00 in PRODUCE and Financial Management to a high of 8.00 in DECIDE. The greater the value of the price elasticity in absolute terms, the more competitive is the market and the stronger is the incentive to compete with price.

Comparing firm to industry elasticity within each market, firm elasticity is greater than industry elasticity in all markets except one. PRODUCE, product 1, has an inelastic firm demand, -0.86, but a highly elastic industry demand, -2.64. However, economic theory argues the opposite should occur as illustrated by the well-known model of Sweezy's Kinked Demand Curve. The Kinked Demand Curve theory contends that firm demand is relatively price elastic compared to industry demand and, as a consequence concludes that stable prices will exist in an oligopoly market. The designers of PRODUCE have reversed the 'kink in Sweezy's Demand Curve which may cause unstable and fluctuating prices to exist in the market.

Looking across Table 4 and examining price elasticities at different price levels another trend becomes apparent. Price elasticity remains constant or increases with increases in standardized prices except for one market. The multinational game, Product A, on the firm level declines in price elasticity as the price of the product increases. This is inconsistent with a wide body of empirical evidence and conventional economic wisdom indicating that price elasticity should rise (or at least remain constant) with increases in product price.

A price elasticity that fills with increases in price could potentially provide an incentive for prices to dynamically rise. However, this would not occur in the Multinational Game for two reasons: (1) price decisions are restricted as previously noted, and (2) price elasticity is greater than one at the start of the simulation, providing an incentive for firms to first lower price rather than increase price. Once prices are lowered, price elasticity increases in the Multinational Market and provides an even greater incentive for the firm to continue to lower price.

Perhaps the most interesting observation drawn from the calculations in Table 4 deals with the variability or sensitivity of price elasticity to changes in the price level; i.e. How quickly does price elasticity change with increases or decreases in price? Some simulated markets have constant elasticity of demand functions which do not change at all with changes in price, these are" DECIDE, PRODUCE-on the firm level, Multinational- Product B on the firm level, and Microsim-on the firm level. In contrast, some markets have price elasticities which are extremely sensitive to changes in price level. For example, in the Executive Came the price elasticity on the firm level rises from -4.00 to -25.20 when standardized price increases from 100 to 150. Such large variations in price elasticity are consistent with consumer behavior theory and are perfectly acceptable models of demand. A potential problem exists, however, with price sensitive elasticities, namely the simulation demand functions tend to "blow-up. As evidence one may examine Table 4. All the simulated markets with <u>positive</u> elasticities are markets that save 'blown-up', i.e. these markets have reached infinitely large and negative price elasticities which lave then turned positive and finite after some price. A positive elasticity indicates that the slope of the demand function is now positive rather than negative. The simulations in this category include: Integrated Simulation, Executive Games OPSIM, and Financial Management. Some of the simulations avoid or eliminate the potential problem of explosive elasticities by limiting pricing decisions by student participants as described earlier in this paper.

FUNCTIONAL FORM AND INSTABILITY

The problem of instability in the demand function may be attributed to the type of functional form chosen by the simulation designer. The functional forms used by each simulation designer were described earlier in this paper, and as previously mentioned the exact demand equations associated with each simulation are specified in appendix A. Unstable demand functions occurred in all the selected simulations which used either linear or nonlinear functional forms; these simulations were: Integrated Simulation, OPSIM, and Financial Management. The log-linear demand functions were unstable in some simulations and stable in others. The instability in the log-linear form, however, can be attributed to the particular way price is entered in the function. In the cases where price was subtracted from a constant and raised to a positive power, the demand becomes undefined when it is increased above the value of the constant. For example, in the Executive Came on the firm level refer to Appendix A) when p>[10] then the term (1O-p) becomes undefined. A similar problem occurs in the Multinational Game for Product B on the industry level when average price, Al', increases above 50. A suggested solution to the problem is to raise price to a negative power or to use the inverse of price, lip, raised to a power, as was done in the following simulations: DECIDE PRODUCE and the Multinational Game on the firm level.

MARKETING AND R&D

Marketing variables (advertising and/or promotion) and product quality variables (research and development) are commonly used as nonprice factors in the demand function. The role of these variables is significantly affected by the degree of diminishing returns imposed in the simulation model. The larger the degree of diminishing returns, the smaller the impact of the non- price variable, thus, a diminished role of the factor in the simulation. Table 5 reports the magnitudes of the elasticities of the Marketing and R&D type variables. The smaller the elasticity, the greater the degree of diminishing returns.

Table 5

Degree of Diminishing Returns to Marketing and Research Development

Simulation	Marketing Variable Firm Level	Marketing Variable Industry Level	Res. & Dev. Variable Firm Level	Res. & Dev. Variable Industry Level
Integrated	0.75	-	0.75	-
Executive	0.70	0.26	0.70	0.13
Decide	1.50	0.10	1.02	0.05
OPSIM	-	-	-	-
PRODUCE	-	-	-	-
Finance	-	-	-	-
Multinational				
-Product A	1.0	0.21	0.5	0.25
-Product B	-	-	1.0	0.5
Microsim	1.45	0.10	0.96	0.05

*A coefficient of 0.5 in the above Table indicates that a 10% increase in the variable will only have an effective impact of 5% in the demand function. A coefficient less than 1 implies diminishing returns; while a coefficient greater than one implies increasing returns.

At *the* industry level, for the simulations examined, both R&D and marketing variables are subjected to substantial diminishing returns. The range of the elasticities varies from .01 to *.5.* In general, at the firm level the degree of diminishing returns was smaller than at the industry level. Thus, these variables play a significant role in differentiation of product at the firm level. Interestingly, two simulations investigated possess firm level elasticities which exceed 1.00. DECIDE has increasing returns to marketing with an elasticity of approximately 1.5. Microsim also has a firm elasticity for marketing greater than one. The experience of the authors of this paper, with these two simulations, indicates that this increasing returns phenomenon at the firm level, causing marketing to be an overly significant competitive influence in the market, even though the industry level has significant diminishing returns. The impact of these variables and whether or not diminishing returns should be large or small depends upon the principal purpose of the simulation. Care must be taken, however, in identifying the degree of diminishing returns. Inadequate diminishing returns can cause the variable to be the "driving variable" in the simulation game. This in turn leads to a winning strategy which can quickly become conventional wisdom to participants.

CONCLUSION

The paper was limited to an analysis of underlying demand functions. Eight simulations, covering most of the functional areas of business, were selected and their underlying demand functions were analyzed. It was found, (Table 3 and Appendix A), that many different modeling forms and techniques were employed by the simulation designers. Some of the simulations incorporated lagged stockouts in the demand function, while others introduced uncertainty, either in actual demand, or in stockout returns. Most of the simulations incorporated an intertemporal movement in the demand analysis. The majority of these used exponential smoothing with the larger values of the smoothing coefficient being applied to the price and marketing variables. As noted, certain of the demand functions were somewhat unstable and yielded unrealistic results, if left unconstrained. The designers, in most cases, imposed constraints on the decision variables to prevent discrepancies between theory and simulation play. The following items note the key advantages and disadvantages of the three forms used:

- •Linear Demand Model - permits variable elasticities. However, the impact of a marginal change in an independent variable is not related to the level of the other independent variables. Tentative elasticity analysis suggests the functional form is sensitive and the elasticities may vary rapidly. Inputs constraints should be applied to insure realistic results.

- •Non linear Demand Model - permits variable elasticities. Tentative analysis suggests it is difficult to separate out the impact of an individual decision on the demand. Highly unstable, and constraints on decision variables are needed.

- •Multiplicative Demand Function - maintains a constant elasticity over range of decision values. The impact of a marginal change in an independent variable is related to the level of the other independent variables. Appears to be stable at the industry level. However, at the firm level care must be taken to avoid "zero" level of decisions.

For stability of price (i.e. Sweezy Kink Demand Theory) care should be taken to insure that firm level price elasticity be larger than the industry level. The "inverse Kink" found in one simulation will probably induce instability in prices.

The elasticities of marketing and R&D variables

Measure the degree of diminishing returns. They in turn suggest the relative importance of those variables in the decision process. The lack of adequate diminishing returns at the firm level, even with substantial diminishing returns at the industry level, induces non price competition and may cause excessive expenditures on that decision variable.

The paper's intent was to criticize or compliment the sampled situations, but rather to present an approach based upon theory that could be used for effective modeling of demand. It is hoped that simulation designers will begin to share, to a greater extent, their knowledge of mathematics and modeling techniques used in the development of computerized business simulations. This type of dialogue should facilitate the growth, design, and sophistication of future simulations; and perhaps, the role of experiential learning.

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Appendix A: Demand Equations

For purposes of comparison, the symbols or notation used in the simulation games have been changed in the table below so that all demand functions share the same notation. The definitions of the symbols are provided at the end of this appendix. (An "A" before any variable refers to the average value of the variable in the industry or market.)

Simulation	Level of Demand	Demand Equation
Integrated Simulation	Firm	$d=E\left(\frac{110M+90R+10000}{2P-50}+2\sqrt{M+R-AM-AR}+(AP-P)\right)$
Executive Game	Firm	$W=\left((10-P)^{2.8}(M+50000)(R+200000)\right)^{0.7}$
Executive Game*	Industry	$D=(11-AP)^{2}\cdot N\cdot(E)^{1.4}\ (S)\cdot 0.78\frac{(AM+100000)(AR+50000)}{(AR+300000)(AR+150000)}$
Decide	Firm	$W=\left(\frac{AP}{P}\right)^{-8}\cdot\left(\frac{M}{AM}\right)^{1.53}\cdot\left(\frac{R}{AR}\right)^{1.02}$ X
Decide	Industry	$D=b\cdot N\cdot(AP)^{-0.9}\cdot(AM)^{0.1}\cdot(S.E)^{0.9}$
OPSIM -Product 1	Firm	$d=15000+1000T+20T^{2}+S+E+500(60-AP)\frac{P}{AP}+500(AP-P)$
OPSIM -Product 2	Firm	$d=19500+500T+20T^{2}+S+E+600(75-AP)\frac{P}{AP}+600(AP-P)$
PRODUCE -Product 1	Firm	$d=bP^{-(.01+.025p)}E^{1.1}(Pr)^{2}$ (Price, P, is set by the simulation in the first level of the game. If inventories exist, price is automatically lowered. If stockouts exist price is automatically raised. In the second level students set price.)
PRODUCE -Product 2	Firm	$d=bP^{-(.25+.011P)}E^{1.1}(Pr)^{2}$
Financial Management	Firm	$d=\frac{(970.75E+616(RAM))\cdot(200-P)}{200-(100+.33(E-100))}$
Multinational -Product A	Firm	$W=\left(\frac{100}{N}+5F+3G+7X+5\bar{R}+5cPV, P/AP\right)^{1.8}$
Multinational -Product B	Firm	$W=\left(\frac{AP}{P}\right)^{3}\left(\frac{R}{AR}\right)$
Multinational -Product A	Industry	$D=6\frac{((DIST\cdot Men)+(AM)^{.5}+(AR)^{.5}+1500)\cdot E\cdot N}{(0.1+(AP/50))}$
Multinational -Product B	Industry	$D=1200N\cdot E\left(1-\frac{AP-30}{20}\right)^{1.3}\left(\frac{AR}{10000}\right)^{.5}$
Microsim	Firm	$W=\left(\frac{AP}{P}\right)^{(2+n/3)}\left(\frac{M}{AM}\right)^{1.5}\left(\frac{R}{AR}\right)^{0.96}$
Microsim	Industry	$D=b(AP)^{-(.5+.004AP)}(AM)^{0.1}(AR)^{.05}(Pr)^{1}(DI)^{1}$

Symbol Definitions

A = an "A" before any symbol refers to the average value of the variable, e.g. AP refers to the average of P which is price

b = parameter used for scaling purposes

c = percent commission on sales. Used only in Multinational Came

d = firm demand

D = Demand for Industry

DI= Disposable Income

E = Economic Index

F = (Distribution centers - average no. of centers); If (IF1)>O then $F=F^{.25}$

G - (Salesmen - average no. salesmen); If (1G1-1)>0 then $G = G^{.25}$

M = Marketing, Advertising, or Promotion variable

N = number of teams or firms

P = price of product

R = Research and Development or Product Quality Variable

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

S = Seasonal Index

T = time or period number

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

$$X=\left(\frac{M}{AM}-1\right)/1.8$$