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PRODUCT STRATEGIES FOR PACKAGED SOFTWARE: AN EXPLORATORY ANALYSIS OF THE SPREADSHEET MARKET

by

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in Partial Fulfillment of
the Requirements of the Degree of
Master of Science in Management

at the

Massachusetts Institute of Technology
June 1993

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ABSTRACT

In this study, we estimate hedonic price equations on data collected for the microcomputer spreadsheet market from 1985 to 1992. We find that real, quality-adjusted prices for spreadsheets have fallen by an average annual rate of 10.4% over this period. Further, we test for and find strong network externality and make effects in the spreadsheet market. In particular, we quantify the value of the Lotus brand name and compatibility with the Lotus 1-2-3 user interface standard. We find that consumers payed a premium for the Lotus brand name in the mid-1980's but that this premium had been dramatically reduced by the early 1990's. We also find that compatibility with the Lotus 1-2-3 interface standard commands a premium in the late 1980's, but is overtaken by a stronger premium for graphic user interfaces in the early 1990's.

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ACKNOWLEDGEMENTS

We wish to thank Erik Brynjolfsson and Chris Kemerer for the idea which sparked this paper and their constant guidance, teaching, and support during this project. We both feel we have been fortunate to have benefitted from such high quality advice and enjoyed the friendship of these fine men.

We owe a debt of gratitude to Bobby Jo Reff of National Software Testing Labs for going the extra mile to provide us with copies of spreadsheet reviews from 1985, 1986, 1987, and 1988. Without his assistance, our data set would have been severely limited. Without the assistance of Bill Kesselring and Paul Wheaton at DataQuest and Jennifer Scholze and Dee Clark at International Data Corporation, data on unit sales would have been completely impossible to gather. We are grateful for their generous help.

Donna Mayo

I would like to thank my family for all their faith in my abilities. I owe much gratitude to Danny for being a wonderful partner in this effort. His good cheer made it possible for me to face this project day in and day out. Also, I would like to acknowledge the late night rides home, encouragement, and nourishing meals provided by Maryalice. Without her, I would have been riding the T at all hours and perhaps too thin. Many thanks.

Danny Young

I would like to thank my family, and particularly my mother, for their support and love. Also Donna for her tireless effort on this project; I worked very hard and still couldn't keep up with her. Above all, I want to thank Tracy, my wife. Her love and service to others inspires me; and the support, love and sweetness that she brings to my life means more to me than she knows.

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I. INTRODUCTION

The packaged software industry reached sales of over $50.6 billion dollars for the year ended 1991.[1] As computers become more and more a part of life, the software industry and the products it offers become increasingly relevant to all members of society.

Software now exists to meet a wide variety of needs, including programs such as databases, spreadsheets, and word processors which form the core of most business' operations, educational software designed to assist children with spelling or math, and games which help while away the hours for countless computer devotees.

As economic goods, software products exhibit several unique qualities, as described by Brynjolfsson and Kemerer (1992):[2]

- The fixed development costs for computer software are high, while the marginal reproduction costs are close to zero.
- In purchasing a software product, consumers are influenced by factors other than purchase price and intrinsic features. The ease of learning the product and the ability to share and access data weigh heavily in the consumer's final choice. These factors create network externalities that lead consumers to prefer products deemed to be "standard."

Brynjolfsson and Kemerer suggest that the combination of five factors -- the large market, the low marginal production cost, the high learning costs for the consumer, the network externalities, and the complementarity relationship with hardware -- make computer software a unique economic good. They further argue that these product characteristics (especially the low reproduction costs) create opportunities for vendors to make pricing decisions primarily on strategic grounds--taking into account the importance of industry standards and the relative size of product installed bases--and less on the costs of manufacturing.

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1 Gary H. Anthes, "Study Cites Software Industry Growth, Piracy Problems," *Computer World*, March 29, 1993, p. 119. This figure includes revenues from what Anthes considered the "core" software industries -- computer programming services, prepackaged software and computer-integrated systems design.

2 Erik Brynjolfsson and Chris F. Kemerer [1992], "Research Proposal on the Economics of Software Standards," MIT Sloan School of Management Working Paper, September 1992.

Software is increasingly seen as the primary component in the hardware/software combination. As one industry observer put bluntly: "The value-added is in the software these days, not the hardware."[3] Yet computer hardware has received much more attention in econometric studies. Perhaps one reason for the lopsided coverage is that many hardware attributes are quite tangible and easily measured (i.e. storage capacity, processor speed, etc.) whereas software attributes tend to be more subjective (i.e. ease of use, "bugginess", "standard" interface, etc.). As software continues to gain in importance and competition grows, a better understanding of the factors leading to software users' adoption of standard products will be vital to software vendors who seek success and longevity in the marketplace. This paper is an attempt to measure which factors are the most important for one specific software product market, microcomputer spreadsheet software, using data for the years 1985 to 1992.

We selected spreadsheets for this study for several reasons. First, spreadsheet software has been hailed as "...the most influential development in management in the last 10 or 15 years"[4]. Second, VisiCalc and Lotus 1-2-3--both spreadsheets--are widely recognized as primary factors in the success of the Apple II and IBM PC platforms, respectively. These two spreadsheets were the original "killer applications", i.e. programs so compelling that consumers buy the hardware platform on which it is implemented just to be able to use the application. Some even maintain that "...behind the success of every new platform lurks a spreadsheet."[5]

> Saying that 1-2-3 "created" the PC industry may be a bit of a stretch. But spreadsheets did legitimize personal computers and push many users toward a specific computer system. Jeffrey Tarter, publisher of the industry newsletter Soft-Letter, says that 1-2-3 is "the single biggest factor in establishing the [IBM] PC as a major platform."[6]

Third, spreadsheet technology has improved dramatically in a short time. Both authors have marveled at the pace of progress and have personally enjoyed the greater analytical capabilities provided by each successive version of spreadsheet programs. Finally,

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3 Jim Seymour in Dvorak, John C. and Seymour, Jim, "Are Software Prices Realistic or a Rip-Off?", *PC-Computing*, Ziff-Davis Publishing, 1989.

4 Abraham Zaleznik, the Konosuke Matsushita Professor of Leadership Emeritus at Harvard Business School, as quoted by Gregg Keizer, "How spreadsheets changed the world," *Lotus*, June 1992.

5 Gregg Keizer, "How spreadsheets changed the world," *Lotus*, June 1992.

6 Ibid.

spreadsheet vendors have engaged in novel pricing and product introduction strategies in recent years as competition in the market has intensified. We would like to identify the empirical rationale for current strategies as well as to evaluate and hopefully improve upon them for the future.

Selected Previous Research

As we mentioned earlier, we believe that network externalities, make effects and compatibility issues play a vital part in the computer spreadsheet market.

A network externality is said to exist for a good when the utility that a user derives from the good increases with the number of *other* people who also consume the good. In other words, the strength of the demand increases as the size of the *network* of existing users increases[7]. For example, consumers only want a video telephone if they believe that many other people who they are interested in calling (and seeing) also own or will own a video telephone.

Network externalities can be caused by a variety of effects. Katz and Shapiro [1985][8] mention the following: 1) Direct, physical effects due to benefits from compatibility, such as the direct benefit that owners of video telephones receive if other people that they call also purchase compatible video telephones. 2) Indirect effects, such as the benefit of owning computer hardware with a large installed base because of the variety of software that will be available to run on that hardware. 3) Availability and quality of post-purchase service, which may vary as a function of the number of units sold. Another cause frequently mentioned is the band-wagon effect which, for example, influences purchases of the latest clothing fashion.

In the market for spreadsheets, network externalities exist primarily because of the benefits of compatibility. Consumers who own a spreadsheet that is compatible with the spreadsheets of many other users benefit in several ways: 1) The ability to exchange data with other users easily; 2) The larger choice of macros, spreadsheet templates, and add-in products developed by other users and software developers; and 3) The ability to use

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7 An excellent reference on this topic is Robert S. Pindyck and Daniel L Rubinfeld, *Microeconomics Second Edition*, Macmillan Publishing Company, New York, 1992.

8 M. Katz and C. Shapiro [1985], "Network Externalities, Competition and Compatibility," *American Economic Review*, June 1985, Vol. 75, pp. 424-440.

another user's spreadsheet without learning a new interface. These benefits also become switching costs. As one micromanager put it;

> "There is no way we're ever going to get away from [the Lotus 1-2-3] installed base. We have too much invested in it and in training people how to use it."[9]

The effect of compatibility on the market for economic goods is a fascinating and complex topic.[10] It has proven to be a vital issue for a variety of industries from telecommunications to shavers. It can impart near-monopoly power to the provider of the standard and in some arenas, compatibility is of such overriding concern that products that are superior but incompatible are rejected. This is known as "excess inertia", or the "lock-in" effect[11]. The endurance of the arguably inferior QWERTY keyboard layout is the classical example.[12]

Katz and Shapiro [1992][13] show the complexities of compatibility by developing a model of consumer choice between two incompatible technologies under different scenarios of product introduction timing and pricing by the producers. Using this model, they have determined that in some conditions, markets where compatibility is important can actually have *insufficient friction*. In other words, entrance by incompatible products is *not as difficult* as it should be for the good of society—the opposite of excess inertia. They also show that under the conditions of their model, when a competitor brings out an incompatible product, the maker of the incumbent product should prefer that the new entrant were compatible. The court actions of Lotus Development corporation to defend its "look and feel" from emulation would suggest that the spreadsheet market did not meet their model conditions.

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9 Quoted by Ed Foster, "Putting the Numbers Right; Spreadsheets remain Pivotal Application," *InfoWorld*, IDG Communications, April 7, 1986.

10 A nice summary of papers dealing with compatibility and network externalities is given by Richard J. Gilbert [1992], "Symposium on Compatibility: Incentives and Market Structure," *The Journal of Industrial Economics*, March 1992.

11 See W.B. Arthur [1989], "Competing Technologies, Increasing Returns, and Lock-in by Historical Events," *Economic Journal*, March, 1989, Vol. 99, pp. 116-131.

12 P. A. David [1985], "Clio and the Economics of QWERTY," *American Economic Review*, Vol. 75, May, 1985, pp 332-336.

13 Michael L. Katz and Carl Shapiro [1992], "Product Introductions with Network Externalities,". *The Journal of Industrial Economics*, March 1992, Vol. 40, pp. 55-84.

Compatibility can also be beneficial. Farrell and Saloner [1987][14] describe four types of benefits from compatibility: network externalities, variety, cost savings, and competitive effects. The spreadsheet market shares in all of these benefits except, perhaps, competitive effects. We have already mentioned several network externalities in the spreadsheet market.

Variety is a benefit of standardization in the spreadsheet market. For example, because each product recognizes a standard file format for spreadsheets, it is possible for consumers to have more variety by mixing and matching productivity software from different vendors (say, WordPerfect for word processing and Excel for spreadsheets) . Cost savings are achieved through standardization in the spreadsheet market in several ways, the most important of which is in the avoidance of training costs to learn a new command set.

Competitive effects are harder to judge in the spreadsheet market. The idea of this benefit is that when products are standardized, firms turn to price as a sole point of competition, thus benefiting society. However, in the spreadsheet market, the *de facto* standard is largely controlled and vigorously defended by one firm, Lotus Development Corporation, thus giving them substantial market power. Also, product differentiation in the spreadsheet market is still possible while still adhering to the *de facto* standard.

Farrell and Saloner [1992] present a model which studies the effect of achieving compatibility *ex post* through converters[15]. Their model shows that converters do not solve all of the problems associated with incompatible products, and in fact, exacerbate some of the incorrect market incentives which exist when incompatible products exist in the market.

Neil Gandal [1992] examined spreadsheet products over the 1986 to 1991 period that operate on the DOS, Windows, and OS/2 operating system platforms. Using data on product attributes, Gandal estimated a hedonic price equation to construct quality-

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14 Joseph Farrell and Garth Saloner [1987], "Competition, Compatibility and Standards: The Economics of Horses, Penguins and Lemmings," *Product Standardization and Competitive Strategy*, as included in H. Landis Gablel (Editor), Elsivier Science Publishers B.V. (North-Holland), 1987

15 J. Farrell and G. Saloner [1992], "Converters, Compatibility, and the Control of Interfaces," *The Journal of Industrial Economics*, March 1992, Vol. 40, pp. 9-36.

adjusted price indexes for spreadsheets. Gandal also used this technique to infer the presence of network externality effects in this market. Gandal concluded that consumers were willing to pay a premium for spreadsheet products that offer file compatibility with Lotus 1-2-3, external links to databases, and local area network (LAN) connectivity. Additionally, Gandal estimated that the quality-adjusted price of spreadsheet software has declined by roughly 15% per year over the period.

This literature, while providing valuable theoretical insights, generally provides little empirical validation of the propositions presented. Except for Gandal's work noted above, our study represents the first comprehensive investigation of network externality effects in computer software. In addition, this paper extends Gandal's work in several ways. First, we consider a significantly larger set of technical product characteristics (49 versus Gandal's 12). Second, we examine products available over the 1985 to 1992 period (Gandal studied spreadsheets introduced from 1986 to 1991). Third, we include spreadsheets for the Macintosh, a platform that represents over 9% of unit sales in the spreadsheet market from 1987 to 1991[16]. Fourth, we include variables for installed base and market share, thereby allowing us to incorporate market input into our results[17]. Finally, in addition to estimating hedonic price equations, we also attempt to estimate demand equations for the spreadsheet market.

In Section II, we describe the research model. In Section III, we discuss the research methodology and data set. In Section IV, we present the main results. In Section V, we describe our efforts at demand estimation. We conclude and suggest areas for further study in Section VI.

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16 Calculation based on units sold information provided by DataQuest.

17 To allow ease of comparison, we applied Gandal's model to our data. These results are provided in Appendix A.

II. RESEARCH MODEL

Hedonic Price Equations

To understand and exploit possible network externalities in the microcomputer spreadsheet market, we must first quantify the value to consumers of characteristics such as program compatibility, vendor reputation, and size of installed base. To quantify these effects, we estimate hedonic price equations. In hedonic estimation, goods are examined as a disaggregated bundle of features, each of which has some price value or penalty attached to it[18]. The price of each product can then be estimated by summing up the values attached to each product attribute.

Early Hedonic Studies

Frederick Waugh , an agricultural economist, conducted the first empirical study directed at understanding the relationship between quality and product pricing in the 1920's.[19] Waugh collected data on the relative prices and characteristics of tomatoes, asparagus, and hot house cucumbers sold at the wholesale market at Boston's Fanueil Hall. Waugh's aim was to assist profit-maximizing farmers in meeting market demand conditions:

> If it can be demonstrated that there is a premium for certain qualities and types of products, and if that premium is more than large enough to pay the increased cost of growing a superior product, the individual can and will adapt his production and marketing policies to market demand.[20]

To accomplish this aim, Waugh chose characteristics he believed to be linked to perceived product quality. For example, to investigate the market for asparagus, Waugh collected data on the number of inches of green color on the asparagus, the average size of the stalks, and on the actual diameter of each stalk. Although Waugh's calculations

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18 Ernst R. Berndt, *The Practice of Econometrics; Classic and Contemporary*, Addison-Wesley Publishing Co., 1991 is an excellent reference on estimating hedonic price indices.

19 Frederick V. Waugh [1928], "Quality Factors Influencing Vegetable Prices," *Journal of Farm Economics*, Vol. 10, No. 2, April 1928, pp. 185-196 as cited in Ernst R. Berndt above, pp. 106

20 Frederick V. Waugh [1928], "Quality Factors Influencing Vegetable Prices," *Journal of Farm Economics*, Vol. 10, No. 2, April 1928, p. 187 as cited in Ernst R. Berndt above, pp.106.

were not entirely accurate[21], they are still an intriguing example of the hedonic technique applied to products with universal familiarity.

Andrew T. Court of the Automobile Manufacturers' Association was the first to study price and quality changes over time.[22] The US government had alleged that General Motors (GM) had been using its monopoly power to extract price premiums for its cars. GM critics cited that the US Bureau of Labor Statistic's official new car price index indicated that prices of new cars had risen by 45% between 1925 and 1935. GM retained Court in 1938 to assess the effects of auto price changes on auto sales.[23] He found that although prices had risen by 45%, the quality-adjusted new car hedonic price index had declined by 53%. In effect, the quality of new vehicle offerings was improving more rapidly than the rise in list prices. Consumers were therefore getting more value for their money spent on a new car. Court's findings provided important input to the government's policy discussions and set a precedent for using hedonic price indexes in general policy determination.

Hedonic Studies of the Computer Industry

Many authors have constructed hedonic price indexes for computers, primarily mainframes and minicomputers[24]. In all cases, quality-adjusted prices have dropped sharply. Cohen [1988] examined personal computers over the 1976 to 1987 period and estimated that average annual quality-adjusted prices had fallen by 25.3% per year[25]. Berndt and Griliches [1990] also studied the microcomputer industry.[26] They found that

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21 Ernst R. Berndt, *The Practice of Econometrics: Classic and Contemporary*, Addison-Wesley Publishing Company, Inc., 1991, p. 108.

22 "Hedonic Price Indexes with Automotive Examples," *The Dynamics of Automobile Demand*, General Motors Corporation, New York, 1939, pp. 99-117 as cited in Ernst R. Berndt.above, pp. 111.

23 Ernst R. Berndt, *The Practice of Econometrics: Classic and Contemporary*, Addison-Wesley Publishing Company, Inc., 1991, p. 110.

24 For a comprehensive summary, see Chapter 4, Section 4 in Ernst R. Berndt, *The Practice of Econometrics: Classic and Contemporary*, Addison-Wesley Publishing Company, Inc., 1991, pp. 117-126.

25 Jeremy Michael Cohen, "Rapid Change in the Personal Computer Market: A Quality-Adjusted Hedonic Price Index 1976 - 1987", Masters Thesis, MIT Sloan School of Management, May 1988.

26 Ernst Berndt and Zvi Griliches, "Price Indexes for Microcomputers: An Exploratory Study", NBER Working Paper #3378, 1990.

average quality-adjusted prices of microcomputers had declined by 28.0% per year over the period 1982 to 1988.

We are aware of only one study that applies the hedonic methodology to microcomputer software. As described above in Section I, Neil Gandal [1992] constructed hedonic price indexes for spreadsheet software over the 1986 to 1991 period and found that quality-adjusted prices had declined by roughly 15% per year over the five year period.

The General Model

The general mathematical model that we proceed with is patterned after Brynjolfsson and Kemerer's [1992] model and expresses product price as a function of a vector of product quality characteristics, and dummy variables to represent the software vendor:

P_i = Real list price of software package i in year t[27]

T_i = Time dummies (years).

H_i = Vector of product quality attributes (e.g. programmable macros)

V_i = Vendor dummies (e.g. Lotus, Microsoft)

Hedonic price equation: **(1)** $P_i = f(T_i, H_i, V_i)$

Price Equation Estimation

We have collected data (discussed in detail below in Section III) on prices, product attributes, vendor, and quantities sold for spreadsheet products by year and version. Our sample set covers the years from 1985 to 1992. The resulting unbalanced panel can be represented as follows:

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27 Real prices are expressed in constant 1987 dollars, as adjusted by the GDP deflator.

Table 1: Unbalanced Panel Data Representation

Product i	Price i	Year i	Attribute1 i	Vendor i	etc.
Lotus 1-2-3 Release 1A	$495	1985	cannot link external cells in formulas	Made by Lotus	.
Multiplan	$195	1985	cannot link external cells in formulas	Made by Microsoft	.
SuperCalc3	$395	1985	cannot link external cells in formulas	Made by Computer Associates	.
.	.	.	.	.	.
.	.	.	.	.	.
Lotus 1-2-3 Release 2.01	$495	1988	cannot link external cells in formulas	Made by Lotus	.
Excel for Macintosh	$395	1988	links external cells in formulas	Made by Microsoft	.
Quattro	$247.50	1988	cannot link external cells in formulas	Made by Borland	.
.	.	.	.	.	.
.	.	.	.	.	.
Excel for Windows	$495	1992	links external cells in formulas	Made by Microsoft	.
Lotus 1-2-3 Release 2.4	$495	1992	cannot link external cells in formulas	Made by Lotus	.
Resolve for Macintosh	$395	1992	links external cells in formulas	Made by Claris	.

Using ordinary least squares multiple regression techniques, we estimate the price equation:

$$(2) \quad P_i = \beta_0 + \beta_{1i} * \text{Year i} + \beta_{2i} * \text{Attribute i} + \beta_{3i} * \text{Vendor i} + \text{Error}$$

Description of Hedonic Variables

We selected variables to measure the quality attributes of products in six main functional areas. These areas are:

1. **Modeling and Analytical Power** – Variables which measure the spreadsheet's ability to handle complex models. For example a spreadsheet may support complex models by including advanced functions, by supporting three dimensionality through cell linking, or by providing customizability through a programmable macro language. In our model, we operationalize this category with cell linking and programmable macros, as will be discussed in Section IV.

2. **Speed and Capacity** – Covers attributes which enhance the spreadsheet's speed (such as sophisticated recalculation algorithms) and which affect the spreadsheet's capacity (such as number of rows and columns or amount of main memory required). No variables from this category were included in our final model because of multicollinearity problems.

3. **Presentation and Output Power** – Measures of the spreadsheet's ability to provide sophisticated output. Variables such as font support, ability to embed charts in worksheets, etc. all measure this functional area. Our model uses the ability to embed charts to represent this category.

4. **Data Manipulation Power and Ease of Use** – Variables which measure the extent and ease with which data can be manipulated once it is in the spreadsheet. For example, support for drag and drop mouse editing and support for global text search and replace both enhance the user's ability to manipulate the spreadsheet data. Our model uses ability to sort by columns and "What You See Is What You Get" (WYSIWYG) interface to represent this category.

5. **Network Externality Effects** – These variables attempt to capture the impact of the network externalities which we believe are significant in this market. For example, compatibility with Lotus on either a file, macro, or menu level is a measure of the effect of the large Lotus 1-2-3 user network. Our model uses the availability of Lotus 1-2-3 menu-tree interface to represent this category.

6. **Make Effects** – Variables which specify the manufacturer capture make effects such as reputation for bug-free programs, advertising, etc. Our model uses a Lotus manufacturer dummy in this category.

The choice of the first four categories conforms closely to the areas considered by professional spreadsheet reviewers when constructing their product reviews. For instance, NSTL made the following statement in its 1989 review of spreadsheets:

> "When choosing a spreadsheet, users still need to find a program with the capacity to handle the required quantity of data, the features to manipulate the data into the required formats, and the ability to output the data in an attractive easily read presentation."[28]

The last two categories are intended to measure the network externality effects and make effects that may exert influence in this market.

In selecting our variables, we have tried to blend popular wisdom as exhibited in the trade press with our own logic and knowledge of spreadsheet product use to arrive at a set of product features to explain pricing in the spreadsheet market. One example of this is our variable called CELLINKF which, as described in Appendix A, indicates a product's ability (or inability) to use a cell reference from an external worksheet in a formula in the current worksheet. As reported in NSTL's 1988 report on spreadsheets:

> Many of the useful functions of three-dimensional worksheets can be simulated in a two-dimensional environment through the use of links...Vendors who hope to maintain the viability of their products will have to scramble to offer linking in future versions.[29]

The sentiment expressed here and in other reviews we read convinced us that the ability to link spreadsheets was a feature worthy of our consideration. In Section IV, we will describe the rationale for the other key variables that comprise our basic model.

Many of the variables we considered are dummy variables that take on the value one if the product exhibits the feature under consideration and zero otherwise. We describe each of the variables and provide graphs and tables of descriptive statistics for each variable in Appendix A.

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28 National Software Testing Laboratories, Software Digest Ratings Report, *Advanced Spreadsheet Programs*, Vol. 6, No. 11, 1989, page 3.

29 "Spreadsheet Programs," *Software Digest Ratings Report*, Vol. 5, No. 6, June, 1988, p. 7-8.

III. RESEARCH METHODOLOGY

Economic Data Sources

To proceed with our analysis of spreadsheet pricing, it was critical to obtain reliable information on units sold and product pricing. DataQuest and International Data Corporation (IDC) both very generously provided data on the spreadsheet market. These two market analysis firms are the leading data sources for information on the software industry (e.g. *Business Week* used data from these two sources in their article in September, 1992 on allegations of anti-competitive practices by Microsoft Corporation[30]). Market coverage for the IDC data set extends from 1986 to 1991; the DataQuest data covers the 1987 to 1991 period[31]. With these combined data, we have unit sales and market share information for 65% of our data observations. Also, we were able to estimate the size of product installed bases for 80% of our final data set based on the available unit sales information.[32]

We were fortunate to have access to both the DataQuest and IDC estimates of unit sales. A comparison of estimates across products and years revealed some discrepancies. However, these differences are generally small in relation to the magnitude of the units sold[33]. Further, neither set of estimates are predictably high or low. Since DataQuest provided market data for a broader range of products in almost every year, we gave preference to DataQuest data when available and, in particular, we used DataQuest's estimate of total market size in calculating our market share values.

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30 Kathy Rebello, Mark Lewyn, and Evan I. Schwartz, "Did Microsoft Shut the Windows on it's Competitors?," *Business Week*, September 28, 1992, p. 32.

31 Product list prices for 1985 were collected from the NSTL spreadsheet reviews.

32 To estimate installed base for a product, we summed units sold in all prior years for all versions of the product. For the initial year a product was sold, we entered the value one rather than zero to enable us to perform demand estimation on the log form of this variable.

33 The average discrepancy was under 7% of total market units sold. The largest discrepancy for a single product was for Microsoft Excel for Windows 3.0 units sold in 1991. DataQuest estimated 627,000 copies of the program sold, while IDC estimated 2,100,000. The largest discrepancy in estimated total units sold in the market was also found in 1991, when DataQuest calculated 4,876,307 against IDC's estimate of 7,029,423.

DataQuest, in addition to the data on unit sales, also provided information on two levels of product pricing. Product official list price and average factory price were supplied for 41% of the observations in our final data set. The average factory price, which is manufacturer's product revenue divided by product unit sales, effectively captures the impact of manufacturers' pricing to the various channels of software distribution, i.e., software retailers, mass merchandisers, and mail order supply houses.[34] Using this data, we estimated the average factory price discount relative to product list price is 58%.

While we would have preferred to have had this data for all products in our sample, the different price information was extremely useful in testing the sensitivity of our results to the level of pricing.[35]

Attribute Data Sources

In gathering our attribute data, we had three aims in selecting a primary source. First, we sought to find a single source that contained consistent and comprehensive information on product features. Second, since we chose to focus on spreadsheet products aimed primarily at business users, this ideal source had to offer excellent coverage of spreadsheet products targeted to this buyer group. Finally, we wanted to include products for the Macintosh. Apple computers now comprise over 12 percent of the installed base of personal computers.[36] While this may seem a negligible share, Apple computers are increasingly finding their way into mainstream business environments and are thus supporting the same sorts of analytical work, often accomplished with spreadsheet software, that their IBM compatible counterparts do in larger number.

A review of the comparative spreadsheet product reviews offered in major computer trade journals quickly revealed that the features reported on varied considerably from year to year. Further, the set of products reviewed in any given year is often limited to

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34 Personal communication dated December 3, 1992 from Bill Kesselring, Industry Analyst, Personal Computing Software at Dataquest.

35 When we tested our model using real factory price (found in Appendix D), we generated results roughly comparable to those obtained when the dependent variable is real product list price. To include as many observations in our data set as possible, we opted for the use of real product list price as the dependent variable.

36 *Standard and Poors Industry Surveys, Computers and Electronic Equipment, October 1991,* Standard and Poors Corporation, 1991.

only the most popular programs. Thus, we could not rely on reviews from any one of these journals entirely even though they are readily available.

One source that did meet our goals was National Software Testing Lab's (NSTL) *Software Digest Ratings Reports*.[37] NSTL began publishing in 1984 and produced at least one and sometimes two issues dedicated to evaluating spreadsheet products in each year. Most of the products covered are business-class spreadsheets. Beginning in 1988, NSTL began publishing a set of reports dedicated to Macintosh products[38], thus allowing us to include most of the more significant Macintosh products in our product set.

Each NSTL report also contains detailed definitions of the product features. These definitions allowed us to confirm that feature information we collected was truly comparable across years for different products, which further increased our comfort with this source. We were able to obtain all of the spreadsheet reports commencing with 1985. Thus, our sample set covers products sold for the years 1985 through 1992.

For the sake of thoroughness, we also supplemented and cross-checked the features information found in the NSTL spreadsheet reports with spreadsheet review articles from *PC Magazine*, *InfoWorld*, *Byte*, *ComputerWorld*, and many others.[39] For instance, we collected every article on spreadsheet products since *PC Magazine's* inception in 1982. The data were also checked against product manuals when available for the more recent products.

Strengths of the Data

We collected consistent information for 49 variables for products that represent at least 75% of units sold in each year for which we have market share information (1986 to 1991). We feel that our coverage of the spreadsheet market offers a good cross-section of products available for different computer platforms and operating systems during this period.

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37 *Software Digest Ratings Reports*, National Software Testing Laboratories, Conshohocken, PA, spreadsheet issues from 1985 to 1992.

38 *Macintosh Ratings Reports*, National Software Testing Laboratories, Conshohocken, PA, spreadsheet issues from 1988 to 1991. Also, we used two issues of *Macintosh Buyer's Alert*, Vol. 1, No. 8 and Vol. 1, No. 9, both issued in 1988.

39 A complete listing of these additional sources is provided in the bibliography.

Limitations of the Data

There are several product attributes that we would have liked to examine in this study for which information was not readily available. For instance, while it is probable that a spreadsheet's speed (e.g., file loading speed, recalculation speed, etc.) enters into a buyer's purchase decision, obtaining comparable estimates of speed for many products is infeasible for a number of reasons. From the NSTL reports, we can obtain speed ratings for only a small fraction (35% or 44 products out of 125) of our data sample. The issue of product speed is further muddied by the fact that advances in microcomputer processor speed throughout the period under consideration make speed rates from year to year incomparable. For example, even though a product itself may not have been improved, speed ratings will vary between two successive years due to the improvement in processor speed alone. We also did not feel justified in constructing a relative speed ranking for products in a given year. Relative rankings would require that a product only a fraction of a second slower in speed be placed a full ranking behind the next fastest product. We do not believe that consumers rank available product choices in this way and thus did not wish to introduce this bias into our model estimation. It may also be true that speed of spreadsheet operations is becoming a secondary issue simply because hardware advances can be counted upon to make up for deficiencies of the software itself, e.g.:

> To be sure, in this era of affordable 386-based machines, recalculation speed is a minor point compared with time spent constructing spreadsheets and preparing output to communicate their results.[40]

Similarly, it may have been interesting to investigate product ratings for ease of use, ease of learning, or other more abstract product qualities. Unfortunately though once again, such ratings are available for only a fraction of our data sample. We do not believe that the lack of this information has seriously hindered our study. Other, more objective measures of product features may proxy for nebulous concepts like ease of use or learning. For instance, products that sport a What You See Is What You Get (WYSIWYG) graphical user interface are often heralded for their ease of use. By quantifying the value of a WYSIWYG interface, we may be able to gain insight into the

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40 Peter Coffee, "Excel 3.0 Sets Spreadsheet Standard," *PC Week*, March 11, 1991, Vol. 8, No. 10.

value-added created by producing a spreadsheet product that is easier to use than others in the marketplace.

We also wish we could have increased our coverage of products for the Macintosh. Because the NSTL *Macintosh Ratings Reports* were not published prior to 1988, our coverage of Mac products early in our sample is not as comprehensive as we had aimed for. However, we did capture the major products in the Mac market in the remaining years. We established through sensitivity testing that excluding the Mac products from our sample does not materially alter the results of our analysis.[41] Therefore, we do not believe that the less than optimal coverage of Mac spreadsheets presents a serious limitation to this study.

Finally, units sold information for 1985 and 1992 products were not available from either DataQuest or IDC in time to be included in this analysis. Since we relied upon product sales information to guide us in repeating prior versions of products in a given year, we believe our product sample for 1992 probably underrepresents the number of different products actually sold during 1992. Using our best judgment and knowledge of product releases, we also constructed an enlarged product set for 1992 by adding six additional products. However, adding these products to the sample in this year did not alter the results significantly, so we omitted them from our final data set.

The Data

We confined our data sample to spreadsheet products geared for business use. This seemed appropriate for two reasons. First, most copies of spreadsheets are purchased by businesses and are thus used in a business environment. Second, business users generally require from their spreadsheets a more powerful set of features than do home users. We felt that mixing products intended for different user groups would perhaps yield confusing results. The practical implication of this decision is that our sample does not include spreadsheets which were distributed via the "shareware" method[42]. Shareware

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41 When we performed our hedonic price estimation excluding Macintosh products, we obtained a slightly higher adjusted R-squared (0.545 versus 0.532); all variables remained significant with comparable coefficient values.

42 When software vendors release a product as shareware, they give permission for the program to be copied freely and given to others. However, they request that if you find that the program fits your needs and you would like to use it regularly that you send payment for the product.

products are aimed primarily at home users and often do not include many features that are taken for granted in the other more sophisticated products, such as complete manuals, customer support, etc. Businesses generally do not buy shareware products.

We also excluded spreadsheet-like products geared mainly towards specialized financial modeling applications such as Javelin and Encore using the same reasoning as above. Although some of these products are capable of the operations typically performed with traditional spreadsheets, financial modeling tools are targeted to a different group of users: As one reviewer wrote:

> Financial-modeling products are not in direct competition with [Lotus] 1-2-3, but rather serve a need that's well beyond the capabilities of general-purpose software. They offer a broad variety of capabilities and features, so that even power users learn only a fraction of the system's capabilities.[43]

To allow us to assess the price and demand relationships more accurately, our data set includes only standalone spreadsheet programs, not spreadsheets sold as part of an integrated package. It is impossible to determine the spreadsheet module's portion of the price of an integrated software package[44].

In total, we collected 125 different product observations, where a new observation is generated for each spreadsheet revision and each year that the revision is offered. For example, Lotus 1-2-3 Release 2.01 counts once for its presence in 1985 and again for its presence in 1986. It is worthwhile to note here that despite the fact that a new version of a product may enter the market, sales of older versions continue. Practically, this results because new products are not neatly introduced at the start of a year nor are older products withdrawn at a year's close. Also, there are users who choose to continue purchasing one, perhaps out-of-date version of a product to maintain guaranteed compatibility with current files and applications or to avoid possible declines in

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43 Robert Moskowitz, "In Volatile Race, Lotus' Lead Remains Strong," *PC Week*, August 15, 1988, Vol. 5, No. 33.

44 Integrated software packages generally include a word processor, a spreadsheet, a communications package, and other modules all in one box for one price. Based on DataQuest data, we estimate that less than 22% of spreadsheets were sold as part of an integrated package from 1987 to 1991. This estimate probably overstates the number of spreadsheets sold in integrated packages because we assume that *all* integrated packages contain a spreadsheet--which is not necessarily true.

productivity associated with learning new features or new ways of working. We used the rule that if either DataQuest or IDC provided units sold information for an prior version of a product, information for that prior product was repeated for that year. This rule proved to be especially robust for Lotus 1-2-3 products where, for example, sales of Lotus 1-2-3 Release 2.01 continued from its release in 1985 through 1991. Taking into account repetition of prior products, there are 39 distinct products (such as Lotus 1-2-3, any revision) in our data sample and 81 distinct product revisions (such as Lotus 1-2-3 Release 2.01 and Lotus 1-2-3 Release 2.2). The table below shows the distribution of the product set by year.

Table 2: Distribution of Sample By Year

Year	Number of Products
1985	13
1986	12
1987	14
1988	15
1989	17
1990	20
1991	23
1992	11

The data set covers spreadsheets made by 19 vendors. The following table details how many data observations are attributable to products from the four major spreadsheet vendors.

Table 3: Distribution of Sample By Vendor

Vendor	Total Data Points	Distinct Products
Lotus	27	4
Microsoft	21	4
Borland	8	3
Computer Assoc.	8	3
Others	61	25

This data set includes 107 data observations for products that operate on the IBM and PC-compatible computer platform and 18 data observations that run on Apple Macintosh

computers. Further, the data set includes products that utilize one of four major operating system environments: MS-DOS, MS-Windows, OS/2, and Macintosh. The following table shows the distribution of the data set over these four operating systems.

Table 4: Distribution of Data Set By Operating System

Operating System	Total Data Points
MS-DOS	89
Macintosh	18
Windows	12
OS/2	6

IV. ESTIMATION OF HEDONIC PRICE EQUATION

Form of Equation

We estimated our hedonic model using both the pure linear and semi-log form of the regression equation. The only difference between these two approaches is that the pure linear form expresses the dependent variable, real product price, in whole dollar form[45]; the dependent variable in the semi-log form is the natural log of real product price. Since all the explanatory variables in our preferred model are zero-one dummy variables, the choice of functional form has no impact on these variables. We obtained a slightly better fit, as measured by a higher value for the adjusted r-squared of the regression, and a smaller standard error using the linear form. We also preferred the linear form to the semi-log since the coefficients obtained from the regression can be interpreted directly as the value added associated with a given product characteristic. Therefore, in this section we report our results using the linear equation form. Readers interested in viewing our results in the semi-log form are referred to Appendix C. In either form, the results of the model are comparable.

Description of Hedonic Model

In arriving at our preferred hedonic model we sought two primary goals: 1) use variables which we feel are most representative of the basic functional categories described in Section III; and 2) achieve a good fit to the data. We tried many combinations of variables that covered these major areas of spreadsheet utility. The preferred model represents the one which we feel best fits the data we had available. The equation is as follows (See Appendix A for variable descriptions):

$$(3)\quad [\text{Real List Price}] = \beta_0 + \beta_1*T86 + \beta_2*T87 + \beta_3*T88 + \beta_4*T89 + \beta_5*T90 + \beta_6*T91 + \beta_7*T92 + \beta_8*\text{CELLINKF} + \beta_9*\text{EMBEDCHT} + \beta_{10}*\text{LOT\_MENU} + \beta_{11}*\text{MFR\_LOT} + \beta_{12}*\text{PROGRAM} + \beta_{13}*\text{SORTCOL} + \beta_{14}*\text{WYSIWYG} + \text{ERROR}$$

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45 Prices are deflated to 1987 dollars with the GDP deflator.

Description of the Base Case Product

The base case product is a business-level spreadsheet sold in 1985 that

- cannot link external worksheets in formulas in the current worksheet
- cannot embed charts on the worksheet
- does not have a Lotus 1-2-3 style menu tree
- is made by a manufacturer other than Lotus Development Corporation
- does not have the ability to create programmable macros
- cannot sort data by column
- does not have a "What You See is What You Get" (WYSIWYG) graphical user interface (GUI).

The constant term estimated in the regression may be interpreted as the price of the base case product in 1985.

Justification of Variable Choice

T86 - T92: These variables control for the year in which the product is observed. They permit us to discern change in price just due to the passing of time.

CELLINKF: The Cell Linking dummy variable is used as one of the best indications of the degree of complexity that the spreadsheet allows in modeling. As described earlier in Section III, the ability to link worksheets was seen as a critical factor to a spreadsheet product's viability in the marketplace. In this sample, CELLINKF becomes available in 1987. Overall, 43.20% of products in this sample offer the ability to use external worksheet cell references in current file formulas.

EMBEDCHT: The ability to Embed Charts on the worksheet is used as an indicator of output and presentation prowess. Users have high expectations of spreadsheet output:

> Presentation and output features become increasingly important with improvements in output technology (i.e., increasing use of laser printers and color printers, the introduction of high-performance microcomputer systems capable of running more highly graphical programs).[46]

It is the most sophisticated of the output variables we collected. In this sample, EMBEDCHT becomes available in 1988. Overall, 34.4% of products in this sample can embed charts on the worksheet.

LOTMENU: The Lotus Menu dummy variable is used to measure the value of the Lotus 1-2-3 user interface. Since Lotus 1-2-3 has been the dominant product in the market since its introduction in 1983, many products have attempted to capitalize on the knowledge of Lotus' installed user base by providing the option to use an exact duplicate of the Lotus 1-2-3 menu tree or a menu tree that operates in the same manner. It also indicates ease of use (for those who already know the 1-2-3 menu tree):

> Slash-F-R to retrieve a file. Slash-F-S to save. Slash-W-E-Y to clear the worksheet. Slash-C, mark the source range, mark the destination. Countless spreadsheet users are familiar with the command sequences popularized by Lotus 1-2-3...Because many of these users are familiar with 1-2-3, the ideal program is one that uses the same command sequence.[47]

> Quattro gives users the choice of selecting any of several optional interfaces. In general, our testers liked the Lotus-style screen and menus, rating 1-2-3 and the five "clone" programs highly for both ease of learning and ease of use.[48]

LOTMENU also represents the highest switching cost for current Lotus 1-2-3 users. The cost of converting existing Lotus 1-2-3 files and macros to new a new spreadsheet platform is likely to be relatively small compared to the cost of retraining all personnel to use a new spreadsheet user interface.

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46 "Advanced Spreadsheet Programs," *Software Digest Ratings Report*, Vol. 8, No. 1, January 1991, p. 3.

47 "Spreadsheet Programs," *Software Digest Ratings Report*, Vol. 7, No. 2, February 1990, p. 7.

48 "Spreadsheet Programs," *Software Digest Ratings Report*, Vol 5, No. 6, June 1988, p. 4-5

In this sample, the percentage of products offering the use of a Lotus-style menu tree peaks at 60% in 1989. Overall, 46.4% of products in this sample offer LOTMENU.

MFR_LOT: The manufacturer Lotus dummy variable is used to test "make" effects[49]. The make effects are likely to be stronger for Lotus than any other manufacturer since they have dominated the spreadsheet market for many years. We use this variable to test whether there is a price premium associated with being the dominant manufacturer in the marketplace. In this sample, 21.6% of products are manufactured by Lotus Development Corporation.

PROGRAM: Support for Programmed Macros is included as an indicator of the customizability of the spreadsheet. We believe this is an important purchasing factor for corporate IS departments. In this sample, PROGRAM reached universal implementation in 1988. Overall, 88.8% of products in this sample permit the user to develop programmable macros.

SORTCOL: The ability to Sort spreadsheet data by Columns is included as an indicator of the spreadsheet's data manipulation features. SORTCOL is a sophisticated measure of data manipulation:

> Sorting the data can quickly clarify the structure of a confusing worksheet. All of the programs can sort by rows; only [several programs] offer the option of sorting by columns.[50]

This variable proved to be an effective discriminator because the percentage of products offering SORTCOL in this sample never exceeds 55% in a given year. Overall, 45.6% of products in this sample can sort data by column.

WYSIWYG: The What You See Is What You Get interface indicates the importance of a Graphical User Interface (GUI) for spreadsheets[51]. Since most of the major PC

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49 Ernst R. Berndt, *The Practice of Econometrics; Classic and Contemporary*, Addison-Wesley Publishing Co., 1991, pp. 128-129.

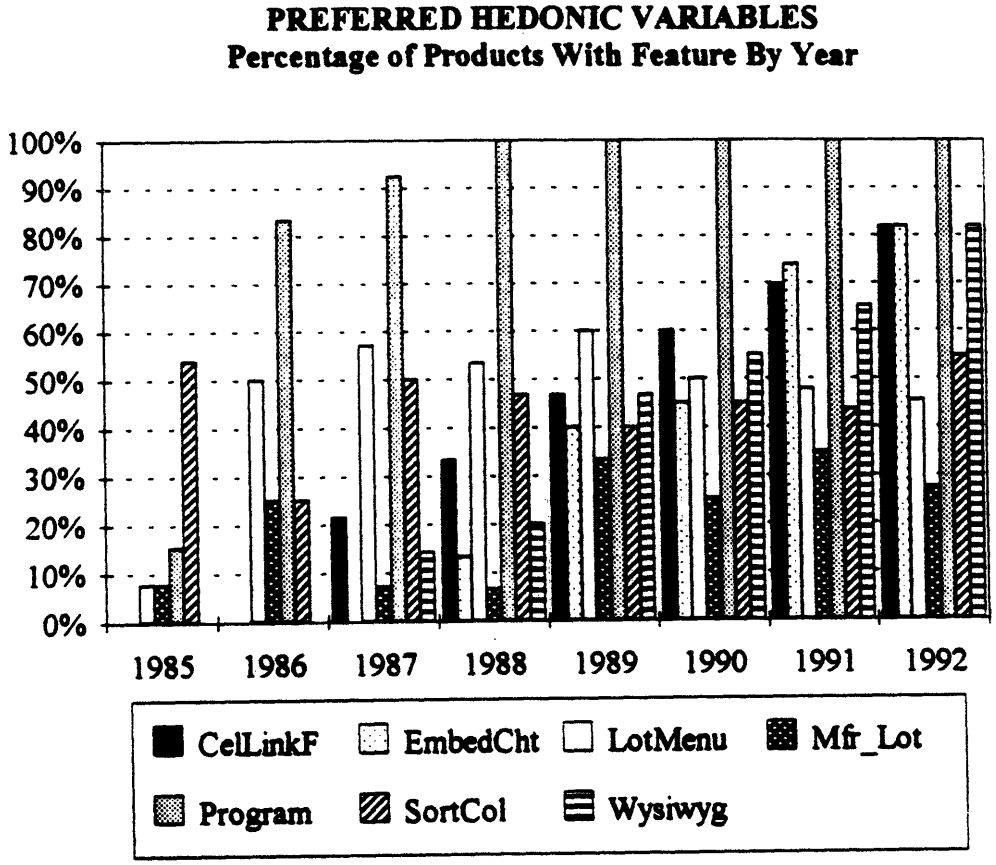
50 "Spreadsheet Programs," *Software Digest Ratings Report*, Vol 5, No. 6, June 1988, Page 6.

51 Traditionally, WYSIWYG refers to an editing environment which accurately displays what a printout will look like. GUI, on the other hand, refers more specifically to an environment where graphical elements on the screen such as pull-down menus are used to control the program (using a mouse). These two qualities are very highly correlated, hence we speak of both interchangeably.

operating systems have turned to GUI interfaces, we wanted to see if and when WYSIWYG becomes important for spreadsheets. WYSIWYG first becomes available in this sample in 1987. By 1992, nearly all (82%) of products in the market offered a WYSIWYG interface. Overall, 39.2% of products in this sample offer a WYSIWYG interface.

Figure 1 below shows the distribution of variables used in our base case hedonic model. Further statistics on these variables may be found in Appendix A.

Figure 1: Distribution of Preferred Hedonic Variables By Year



Results of the Hedonic Price Equation Estimation

The results of our estimation using this model are shown in the following table:

Table 5 : Results of the Hedonic Price Equation Estimation

BASE CASE HEDONIC MODEL
(Real List Price is Dependent Variable)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
C	151.893	4.778	0.000
T86	-23.743	-0.452	0.652
T87	-86.637	-1.560	0.122
T88	-105.417	-1.826	0.070
T89	-156.379	-2.726	0.007
T90	-174.840	-3.063	0.003
T91	-259.380	-4.465	0.000
T92	-263.390	-4.133	0.000
CELLINKF	59.782	2.044	0.043
EMBEDCHT	124.720	3.269	0.001
LOTMENU	66.797	2.632	0.010
MFR_LOT	155.402	5.058	0.000
PROGRAM	117.448	2.378	0.019
SORTCOL	125.238	5.169	0.000
WYSIWYG	58.923	1.844	0.068
N	125		
S.E. of Regression	100.252		
R-Squared	0.582		
Adjusted R-Squared	0.528		

These results show that quality-adjusted prices for spreadsheet software have declined steadily since 1985 at a real average annual rate of 10.4%, holding features constant[52]. Also, this decline has been consistently monotonic over the 1985 to 1992 period, which is to say that the time-associated drops in product value are all in the same downward direction. All of our other variables had a positive effect on the price charged for spreadsheets. The figure below compares the real quality-adjusted price for spreadsheets with observed nominal and real average prices in each year. The real quality-adjusted price is calculated for the cost of a product with the same features offered as Lotus 1-2-3

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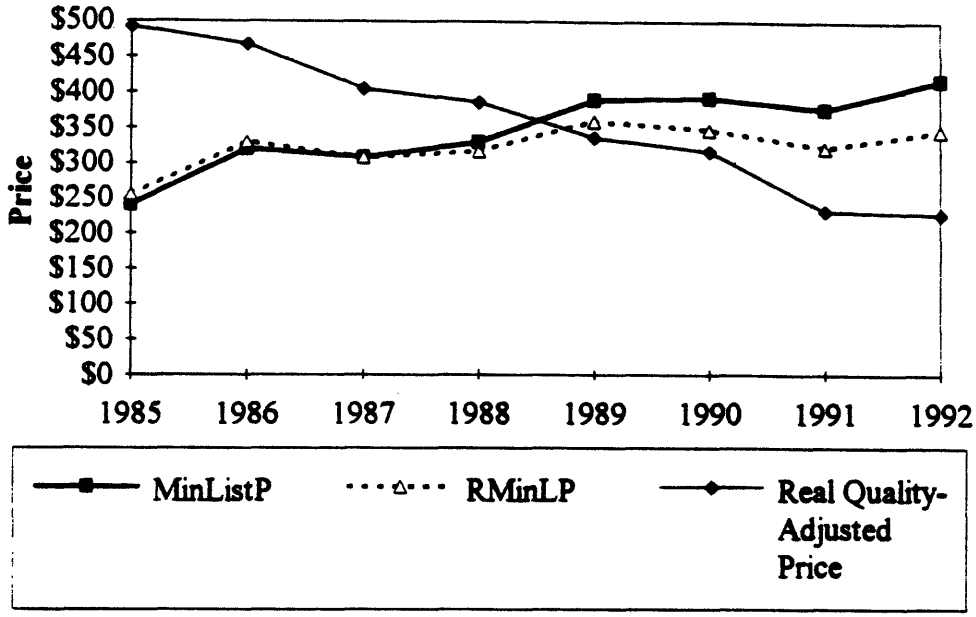
[52] We held LOTMENU, MFR_LOT, and PROGRAM constant in this calculation for illustration. This results in a typically priced 1985 product such as Lotus 1-2-3 Ver. 1A.

version 1A in 1985 (LOTMENU, MFR_LOT, PROGRAM). This product, costing $491 in 1985, is valued at only $228 in 1992.

Figure 2: Actual Average Product Price vs. Quality-Adjusted Price



Lotus manufacture is shown to have a highly positive effect on price, just as we expected. Large price premiums are also obtained for the ability to sort by columns, embed charts, and use programmable macros.

Although Lotus 1-2-3 menu compatibility does show a price premium of $67, we expected a larger effect relative to the other variables. In fact, the premium for Lotus menu compatibility is large relative to the other variables if the model is restricted to data from 1988 to 1990, as we will present later. These results make it easy to appreciate Paperback Software's troubles when they were prohibited by the courts from including

the Lotus 1-2-3 menu tree (worth $67 according to these results) in their $99 VP Planner Plus![53]

Comparison of Actual and Predicted Product Price

In Table 6 below, we apply our base case model to a range of products selected from 1990. As the table demonstrates, this hedonic model does a good job of explaining the observed prices for products in the spreadsheet market, especially for those products that operate on the DOS operating system. To arrive at the predicted list price of a given product, we summed the regression constant of $151.89 and the time coefficient of ($174.84) for 1990 with the values associated with the attributes present in the product. For example, the first product listed in Table 6, Excel for Windows, earns $151.89 as the constant term, $59.78 for its cell linking ability, $117.44 for its ability to create programmable macros, $125.23 for its ability to sort data by column, and $58.92 for its WYSIWYG interface, and is penalized ($174.84) for being in the spreadsheet market in 1990. A positive error can be interpreted to mean that the actual list price was higher than the predicted value, suggesting perhaps that the product was overpriced relative to other products in the market. Similarly, a negative error can be interpreted to mean that the actual list price was lower than the predicted price, implying perhaps that the product offers more features per dollar of price, an attractive features/price ratio.

The two "Lotus Knock Offs" priced out below, Twin Advanced and VP-Planner, each offer the same functionality of the Lotus 1-2-3 2.X series products at only a fraction of the cost of the Lotus 1-2-3 product. Each product appears to offer an attractive features/price relationship, as our model estimates a value to consumers in excess of the price charged for the product. These products make clear the power of make effects in this market: just by changing the make to Lotus Development Corporation would bring them to the same premium price level commanded by "true" Lotus 1-2-3 products.

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53 Lotus Development Corp. v. Paperback Software International, 740 F. Supp. 37 (D. Mass. 1990).

Table 6: Basic Model Predictions for Selected Products in 1990

Product Name (Operating Sys)	Actual Real List Price (A)	Predicted Real List Price (B)	Error (A-B)	Cel LinkF	Embed Cht	Lct Menu	Mfr_ Lot	Program	Sort Col	Wysi wyg
Excel (WIN)	$349.95	$338.44	$11.50	$59.78	$0.00	$0.00	$0.00	$117.45	$125.24	$58.92
Full Impact (MAC)	$349.95	$463.16	($113.22)	$59.78	$124.72	$0.00	$0.00	$117.45	$125.24	$58.92
Lotus 1-2-3 Ver. 3.0 (DOS)	$527.13	$501.20	$25.93	$59.78	$124.72	$66.80	$155.40	$117.45	$0.00	$0.00
Quattro Pro (DOS)	$438.54	$404.72	$33.82	$59.78	$124.72	$66.80	$0.00	$117.45	$0.00	$58.92
Twin Advanced (DOS)	$105.43	$161.30	($55.87)	$0.00	$0.00	$66.80	$0.00	$117.45	$0.00	$0.00
VP-Planner (DOS)	$87.71	$161.30	($73.59)	$0.00	$0.00	$66.80	$0.00	$117.45	$0.00	$0.00
Wingz (OS/2)	$442.08	$337.93	$104.16	$59.78	$124.72	$0.00	$0.00	$117.45	$0.00	$58.92

Hedonic Price Equation Estimations for Three Time Periods

We estimated our base case model for three time periods as follows:

- Years 1985 through 1987
- Years 1988 through 1990
- Years 1991 and 1992

Dividing the years into three groups allowed us to have at least 30 data points in each estimate and to include variables which otherwise would have been deleted due to lack of implementation or universal implementation.

Even with three groups, the model needed to be modified slightly due to features which either were not implemented by any product or were universally implemented in a period. The first period does not include Embedded Charts because no spreadsheet in this period had yet implemented this feature. The second and third period models do not include Programmable Macros because this feature was universally implemented by the products in our data in these two periods.

Tables 7 through 9 below present these estimates over time:

Table 7: Hedonic Price Equation Estimation for Years 1985 to 1987

BASE CASE HEDONIC MODEL — YEARS 1985 - 1987
(Real List Price is Dependent Variable)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
C	97.9344	3.3007	0.002
T86	22.7310	0.5084	0.615
T87	-13.2075	-0.2557	0.800
CELLINKF	95.7213	1.0318	0.310
LOTMENU	-6.5889	-0.1600	0.874
MFR_LOT	313.3341	6.1143	0.000
PROGRAM	94.6912	2.1643	0.039
SORTCOL	219.8715	7.0313	0.000
WYSIWYG	-100.0022	-0.9784	0.336
N	39		
S.E. of Regression	83.4517		
R-Squared	0.7863		
Adjusted R-Squared	0.7294		

Table 8 : Hedonic Price Equation Estimation for Years 1988 to 1990

FINAL HEDONIC MODEL — YEARS 1988 - 1990
(Real List Price is Dependent Variable)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
C	158.4357	3.4059	0.001
T89	-40.0497	-1.0342	0.301
T90	-45.9944	-1.1824	0.244
CELLINKF	114.9398	2.7174	0.009
EMBEDCHT	52.8943	0.9752	0.335
LOTMENU	116.8979	2.9247	0.005
MFR_LOT	118.0560	2.5110	0.016
SORTCOL	69.9972	1.5859	0.120
WYSIWYG	50.0602	1.1649	0.251
N	52		
S.E. of Regression	103.9349		
R-Squared	0.5680		
Adjusted R-Squared	0.4876		

Table 9 : Hedonic Price Equation Estimation for Years 1991 to 1992

FINAL HEDONIC MODEL — YEARS 1991 - 1992
(Real List Price is Dependent Variable)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
C	113.5772	2.4315	0.022
T92	-5.1968	-0.1880	0.852
CELLINKF	-16.9384	-0.4088	0.686
EMBEDCHT	95.0323	1.2452	0.224
LOTMENU	74.5805	1.8132	0.081
MFR_LOT	25.4173	0.4774	0.637
SORTCOL	16.3852	0.4436	0.661
WYSIWYG	151.7112	2.7001	0.012
N	34		
S.E. of Regression	72.7694		
R-Squared	0.7454		
Adjusted R-Squared	0.6768		

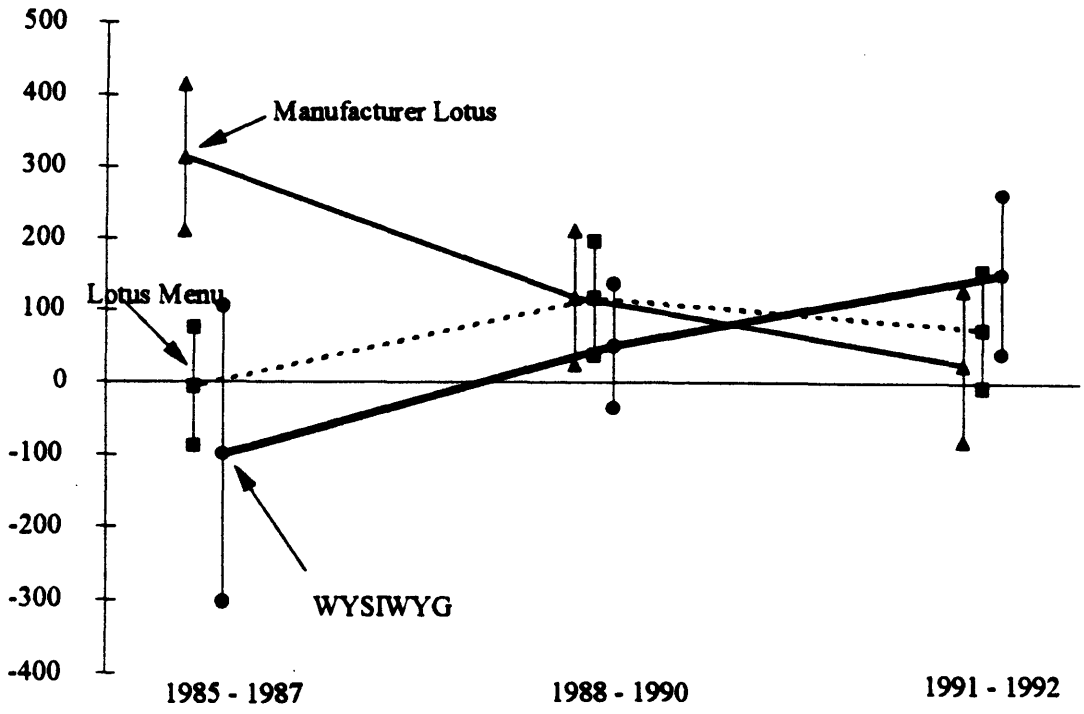
Figure 3 below summarizes these results by showing the movement of three variables: MFR_LOT, LOTMENU and WYSIWYG during the three periods. The vertical lines on the graph represent 95% confidence intervals around each estimate. The most striking result from these estimates is the steep decline in the value of the Lotus make effect. Manufacturer Lotus commands a premium of $315 in the first period, $119 in the second period, and falls to an insignificant factor in the model in the third period.

Also striking is the opposite behavior of the WYSIWYG variable. The WYSIWYG interface, showing an insignificant value in the first period increases to a distinct premium of $151 in the third period. The third period corresponds roughly to the release of Microsoft Windows 3.0, the enormously successful GUI environment for MS-DOS based machines. We believe the importance of the WYSIWYG interface for spreadsheets was influenced by the release of Windows 3.0.

Lotus 1-2-3 menu tree compatibility is insignificant in the first period (while Lotus was still establishing itself as the *de facto* standard) and then peaks in the second period. The third period shows a decline in the importance of Lotus 1-2-3 menu tree compatibility. We hypothesize that the emergence of GUI environments, with their standardized user interfaces of pull-down menus, etc. reduced the importance of the Lotus menu tree. It is

interesting to note that Lotus was still spending a good deal of time and money defending its menu tree in the early 1990's even as this decline in the menu tree's value was taking place.

Figure 3 : Change in Price Estimate Variables Over Time



To confirm that the estimates presented above for LOTMENU, WYSIWYG, and MFR_LOT were indeed statistically significantly different in each time period considered, we compared two regressions, one restricted and one unrestricted, using an F-test[54]. The restricted regression was conducted on pooled data and can be expressed in mathematical form as follows:

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[54] Robert S. Pindyck and Daniel L. Rubinfeld, *Econometric Models and Economic Forecasts*, McGraw-Hill, 1991, pp. 111.

(4) $[\text{Real List Price}] = \beta_0 + \beta_1 * \text{PERIOD2} + \beta_2 * \text{PERIOD3} + \beta_3 * \text{LOTMENU1} + \beta_4 * \text{LOTMENU2} + \beta_5 * \text{LOTMENU3} + \beta_6 * \text{MFRLOT1} + \beta_7 * \text{MFRLOT2} + \beta_8 * \text{MFRLOT3} + \beta_9 * \text{WYSIWYG1} + \beta_{10} * \text{WYSIWYG2} + \beta_{11} * \text{WYSIWYG3} + \text{ERROR}$

where: PERIOD2 is a dummy variable that equals one if the observation belongs to the second (1988-1990) period and zero otherwise

PERIOD3 is a dummy variable that equals one if the observation belongs to the third (1991-1992) period and zero otherwise.

LOTMENU1 is the product PERIOD1*LOTMENU. This variable equals one if the observation belongs to PERIOD1 and the product has a Lotus 1-2-3 style menu tree.

The other variables are defined similarly.

The unrestricted regression was limited to variables shown below in Equation 5:

(5) $[\text{Real List Price}] = \beta_0 + \beta_1 * \text{LOTMENU} + \beta_2 * \text{MFRLOT} + \beta_3 * \text{WYSIWYG} + \text{ERROR}$

The F-test yielded a test statistic of 2.42695 which is significant at the 0.0185 value. The critical value required to conclude that the restricted regression provides significantly more explanatory power was 2.01987. Table 10 presents the results of the restricted regression. The regression in this form provides the benefit that coefficients estimated for variables in each sample period can be compared directly and their significance level determined. Further, the results from this regression confirm that the value of LOTMENU peaks in the 1988-1990 period, MFR_LOT has declined substantially by the 1991-1992 period, and that WYSIWYG commands a significant premium of over $200 by the 1991-1992 period.

Table 10 : Results of Pooled Restricted Regression

POOLED RESTRICTED REGRESSION RESULTS
(Real List Price is Dependent Variable)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
C	264.751	10.966	0.000
PERIOD2	-44.865	-1.145	0.255
PERIOD3	-123.574	-2.558	0.012
LOTMENU1	-24.648	-0.571	0.569
LOTMENU2	83.003	2.081	0.040
LOTMENU3	59.028	1.000	0.319
MFRLOT1	270.265	4.357	0.000
MFRLOT2	110.422	2.363	0.020
MFRLOT3	39.611	0.620	0.536
WYSIWYG1	130.258	1.557	0.122
WYSIWYG2	127.300	3.639	0.000
WYSIWYG3	210.325	4.716	0.000
N	125		
S.E. of Regression	113.245		
R-Squared	0.452		
Adjusted R-Squared	0.398		

Variations on the Basic Hedonic Model

In this section, we add variables of interest to our base case hedonic equation. Many of the additional variables we consider here may indicate the presence of additional network externality effects in the spreadsheet market. In the discussion that follows, we present several variations of the basic model and briefly consider the results. Appendix A contains definitions and descriptive statistics for variables which are in addition to the base case model.

Base Case Hedonic Model with Variables for Major Manufacturers

As the spreadsheet market has evolved, there are effectively four major vendors of spreadsheet products. To test the impact of make effects other than Lotus Development Corporation, we have also included make effect variables for Borland (MFR_BORL), Microsoft (MFR_MS), and Computer Associates (MFR_CA). The results are shown in

the table below. Notice that none of these added variables are shown to be statistically different than zero, while the Lotus variable remains highly positive and significant.

Table 11 : Results of the Hedonic Price Equation Estimation Including Make Effect Variables for Major Manufacturers

BASE CASE HEDONIC MODEL INCLUDING MAKE EFFECT VARIABLES
(Real List Price is Dependent Variable)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
C	150.989	4.713	0.000
T86	-21.530	-0.408	0.684
T87	-77.104	-1.369	0.174
T88	-94.453	-1.613	0.110
T89	-148.916	-2.574	0.011
T90	-165.332	-2.864	0.005
T91	-254.918	-4.349	0.000
T92	-261.535	-4.079	0.000
CELLINKF	50.818	1.650	0.102
EMBEDCHT	120.228	2.958	0.004
LOTMENU	48.373	1.620	0.108
MFR_LOT	177.625	5.203	0.000
MFR_BORL	53.789	1.363	0.176
MFR_MS	3.990	0.129	0.897
MFR_CA	40.976	0.933	0.353
PROGRAM	112.863	2.271	0.025
SORTCOL	121.261	4.594	0.000
WYSIWYG	64.905	1.899	0.060
N	125		
S.E. of Regression	100.530		
R-Squared	0.591		
Adjusted R-Squared	0.526		

Base Case Hedonic Price Equation with Variables for Operating Systems

We also modified our basic hedonic model to include variables for operating system platform. We removed the WYSIWYG variable since much of what it measures is correlated with operating system. All Macintosh and Windows spreadsheets, for example, offer a WYSIWYG interface. If we leave WYSIWYG in the regression, it becomes insignificant.

We find from this modified model that OSWIN is a statistically significant predictor of price in this market. Much of this, we believe, is due to the fact that OSWIN also encapsulates the benefits of WYSIWYG. In fact, our basic model with just the modification of replacing WYSIWYG with OSWIN yields nearly identical results.

Table 12 : Results of the Hedonic Price Equation Estimation Including Operating System Variables

BASE CASE HEDONIC MODEL INCLUDING OPERATING SYSTEM VARIABLES (Real List Price is Dependent Variable)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
C	146.084	4.568	0.000
T86	-22.476	-0.426	0.671
T87	-85.508	-1.531	0.129
T88	-104.859	-1.807	0.074
T89	-144.891	-2.529	0.013
T90	-169.276	-2.958	0.004
T91	-260.363	-4.453	0.000
T92	-274.746	-4.244	0.000
CELLINKF	54.092	1.682	0.095
EMBEDCHT	157.642	4.411	0.000
LOTMENU	73.581	2.674	0.009
MFR_LOT	158.325	5.125	0.000
PROGRAM	114.913	2.309	0.023
SORTCOL	135.365	5.536	0.000
OSWIN	82.534	1.991	0.049
OSMAC	22.776	0.604	0.547
OS2	22.987	0.467	0.642
N	125		
S.E. of Regression	100.9879		
R-Squared	0.5832		
Adjusted R-Squared	0.5214		

Base Case Hedonic Model with Cross-Platform Compatibility Variables

We felt that assessing the value of cross-platform compatibility would be interesting to include as a test of network externality effects. Cross-platform compatibility is here defined as the condition where a spreadsheet product offers a version on more than one

operating system platform. For example, the product Wingz offers versions that run on Macintosh, OS/2, and Windows. The result of adding variables to capture the impact of cross-platform compatibility effects is shown in Table 13 below. None of these variables is shown to be statistically significant.

Table 13: Results of the Hedonic Price Equation Estimation Including Cross-Platform Compatibility Variables

BASE CASE HEDONIC MODEL INCLUDING CROSS PLATFORM COMPATIBILITY VARIABLES
(Real List Price is Dependent Variable)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
C	147.456	4.619	0.000
T86	-24.837	-0.476	0.635
T87	-93.849	-1.694	0.096
T88	-114.543	-1.986	0.050
T89	-161.387	-2.806	0.006
T90	-191.010	-3.301	0.001
T91	-279.684	-4.640	0.000
T92	-277.292	-4.160	0.000
CELLINKF	67.448	2.264	0.026
EMBEDCHT	125.461	3.161	0.002
LOTMENU	77.886	3.004	0.003
MFR_LOT	142.469	3.885	0.000
PROGRAM	116.995	2.364	0.020
SORTCOL	129.555	5.237	0.000
WYSIWYG	48.269	1.379	0.171
OP_DOS	-50.469	-1.090	0.278
OP_MAC	30.213	1.132	0.260
OP_OS2	35.103	1.140	0.257
OP_WIN	0.861	0.029	0.977
N	125		
S.E. of Regression	99.540		
R-Squared	0.603		
Adjusted R-Squared	0.535		

V. ESTIMATION OF DEMAND EQUATION

Challenges in Measuring Demand Curves for Goods with Network Externalities

In attempting to estimate a demand curve for a good with network externalities such as spreadsheets, there are unique challenges.

When we measure price versus quantity sold, we are measuring not just the demand curve, but the market equilibrium between both the demand curve and the supply curve. In some cases, the demand curve remains relatively constant, but the amount supplied by producers varies over time. This means the market equilibrium point varies over time in such a way that the demand curve is exposed.

With goods that have network externalities, however, the demand curve shifts outward as the quantity sold becomes larger because the larger network makes the good more attractive to consumers. In Figure 4 below, the demand starts at the line labeled D200 (Demand when the size of the network is 200,000). As the quantity sold increases to 400,000, 600,000 etc., the demand curve shifts, going through D400, D600, etc. The effect of this shift on our measurement is that we observe a much flatter demand curve, as indicated by the "Observed Demand" line[55]. Note that the observed demand can be upward sloping even when actual demand is downward sloping.

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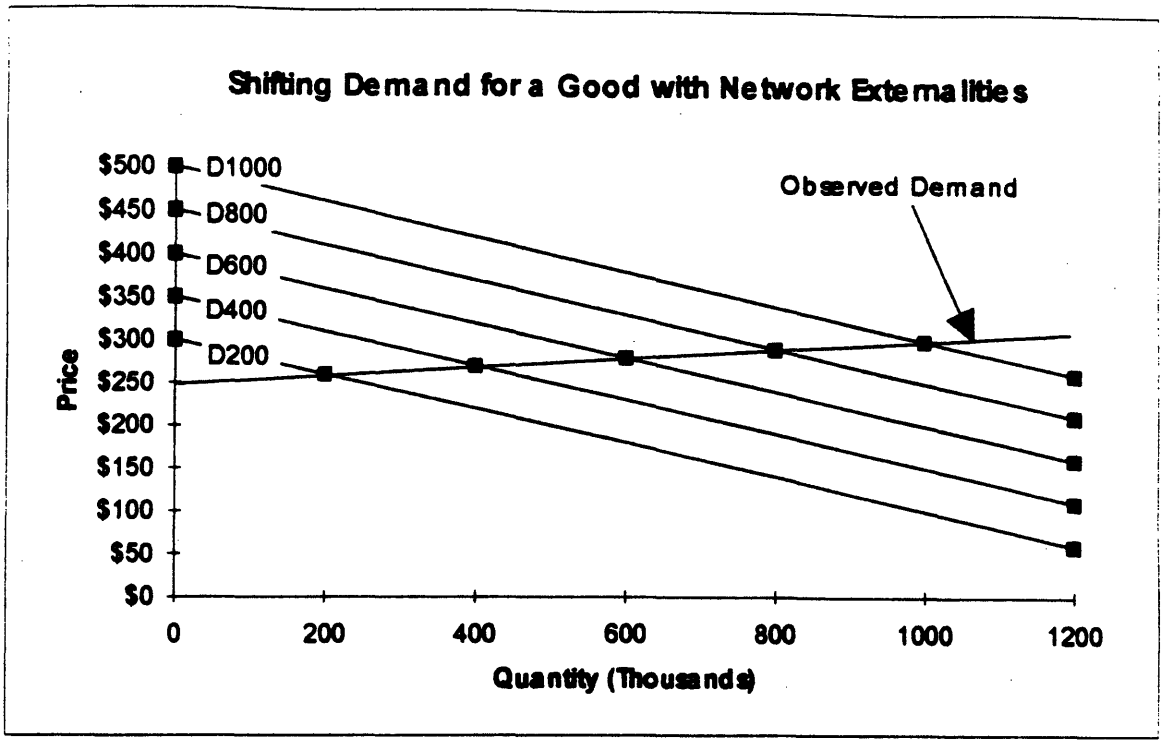
55 Robert S. Pindyck and Daniel L Rubinfeld, *Microeconomics Second Edition*, Macmillan Publishing Company, New York, 1992, pp. 118-120.

Figure 4: Effect of Network Externality on Observed Demand



In situations such as this where both supply and demand curves change over time, one cannot estimate demand using ordinary least squares because the simultaneity biases the slope of the demand curve upward[56]. Instead, one must employ a technique such as using instrumental variables which are correlated with demand, but uncorrelated with supply. We leave this step to further research. However, we do present here the results of an ordinary least squares estimate of demand which shows an upward sloping demand curve, suggesting that the network externalities do, in fact, make ordinary least squares an inadequate estimator.

Results of the Demand Equation Estimation

The OLS demand estimation model takes the following mathematical form:

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[56] Ernst. R. Berndt, *The Practice of Econometrics: Classic and Contemporary*, Addison-Wesley, 1991, pp. 324. Also, personal communication with Erik Brynjolfsson on May 5, 1993.

$$(6) \quad LNUNITS = \beta_0 + \beta_1 * T87 + \beta_2 * T88 + \beta_3 * T89 + \beta_4 * T90 + \beta_5 * T91 + \beta_6 * LNINBASL + \beta_7 * LNRMINLP + \beta_8 * MFR\_LOT$$

A description of each variable is shown in the table below:

Table 14: Demand Equation Variables

Demand Equation Model Independent Variables	
Variable	***Justification for Inclusion***
T87 - T91	Year variables to discern changes in units sold over time.
LNINBASL	Natural log of the installed base of this spreadsheet (all versions). Used to attempt to discern the network externality effect of the installed base.
LNRMINLP	The natural log of the real list price of the spreadsheet is included to test the effect of price on demand.
MFR_LOT	Dummy variable equals one if the manufacturer is Lotus. This is included to test the effect of the industry leader and *de facto* standard holder on units sold.

The results of our estimation using this model are shown in the following table:

Table 15: Results of the Demand Price Equation Estimation - Log Form

BASE CASE DEMAND MODEL
(Log of Units Sold is Dependent Variable)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
C	7.2783	3.9876	0.000
T87	-1.2203	-1.6932	0.095
T88	-1.9744	-2.7004	0.009
T89	-2.2335	-2.9920	0.004
T90	-2.6766	-3.5255	0.001
T91	-2.5411	-3.6910	0.000
LNINBASL	0.1790	5.5147	0.000
LNRMINLP	0.7439	2.2960	0.025
MFR_LOT	0.3673	0.8933	0.375
N	81		
S.E. of Regression	1.3713		
R-Squared	0.3878		
Adjusted R-Squared	0.3198		

VI. CONCLUSIONS

Major Findings

This study has investigated the issue of pricing in the market for packaged spreadsheet software by applying hedonic price estimation techniques. Our results confirm that the pace of quality improvements for products in this market has outpaced the rise in product price during the 1985 to 1992 period. In fact, we estimate a real quality-adjusted price decline of 10.4% per year for a typical spreadsheet first offered in 1985.

It has been argued that the spreadsheet market has strong network externalities (and make effects) because of consumer's desire to share spreadsheet information and because of the cost of learning the user interface. We have found that the empirical data support the hypothesis that the spreadsheet market is influenced by strong network externality and make effects.

However, we have also discovered that the dominant supplier of spreadsheets, Lotus Development Corporation, has not wielded as much market power in recent years as in the past. Indeed, both the Lotus make effect and the value of compatibility with the Lotus 1-2-3 menu structure become statistically insignificant in 1991 and 1992, according to our results.

We also tested other spreadsheet attributes that indicate a product's 1) ability to create complex models, 2) ease of use, 3) data manipulation power, and 4) output capabilities. These attributes had significant influence on spreadsheet prices. Of particular interest was whether the spreadsheet had a "What You See Is What You Get" (WYSIWYG) display and interface. This attribute grows in value over time until by 1992 it is valued more highly by users than the Lotus 1-2-3 menu tree. We believe that graphical user interfaces, with their fairly standard layout of menus and use of the mouse input device, has become the new standard user interface. Although Macintosh products have used this interface for many years, it appears from our data that graphical user interfaces gained in importance most impressively in the early 1990's, coinciding with the release of Microsoft Windows 3.0 for DOS machines.

With this suspected switch in standard spreadsheet interface from Lotus 1-2-3 menu structure to GUI, the market has undergone drastic changes. Although we do not have unit sales data for 1992 or 1993, we have observed evidence of falling prices in the

spreadsheet market which may be explained, in part, by the fact that the dominant interface is no longer controlled by one company wielding near-monopoly powers in the marketplace. Although intellectual property rights on graphical user interfaces are by no means undisputed, the general elements of the interface have not been successfully defended.[57]

Implications for Packaged Software Strategy

There may be strategic benefits to software vendors of applying the hedonic approach to product pricing in the markets in which they compete. While the hedonic approach, by definition, looks backward in time, we feel that the results of such an analysis can provide vendors with better insight into market trends. This is particularly true for cross-sectional hedonic estimation, where the relative values of product characteristics can be traced through time. A cross-sectional hedonic analysis may have saved Lotus significant legal fees in protecting their menu structure and perhaps signaled that the time had come to develop their own products with a graphical user interface. However, it would not have provided Lotus with the intuition to be the first vendor to offer a product with a graphical user interface.

We believe success in software relies upon a mixture of 1) innovation, 2) an understanding of the value to users of different product attributes, and 3) a knowledge of and an ability to harness the power of network externality effects. Effective implementation of each of these elements is critical in a market with significant network externalities such as the spreadsheet market. Our analysis provides insight into both product attribute importance and the strength of network externality effects.

Suggestions for Further Research

As we briefly explored in Section VI, the question of demand estimation for the spreadsheet market is complex because of the shifting demand curves due to network

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57 See Lee T. Gesmer, "Recent Developments in Software Protection," *Massachusetts Lawyers Weekly*, November 16, 1992 for a good description of Apple Computer's suit alleging that Microsoft's Windows product infringes on the "look and feel" of the Macintosh operating system. In the end, only very specific attributes, such as the appearance of the Mac Trash icon, were ruled to be copyrightable. Pull-down menus and the use of icons in general were considered to be in the public domain.

externalities. However, we feel that further research in this area could yield valuable insights.

Additionally, it would be interesting to conduct similar analysis in other software categories. Such research may uncover characteristics which can be generalized to the entire packaged software industry.

In conclusion, although cutting edge technology is important in the microcomputer spreadsheet market, it must be technology which provides business value as evidenced by people's willingness to pay for it. Because of network externalities, a technologically advanced but "incompatible" new feature can have ***negative*** value to customers. This thesis has contributed to our understanding of the business value of software technologies and how they are affected by compatibility issues.

APPENDIX A: DESCRIPTION OF VARIABLES AND DESCRIPTIVE STATISTICS

In this appendix, we provide detailed definitions of each variable for which we collected data. Additionally, we display the distribution of the data in graph and table form both by year and for the complete 1985-1992 sample period. The mean values for zero-one dummy variables can be interpreted as the percentage of products in the sample that exhibit a given feature. Table 40 at the very end of this appendix provides a listing of variables ordered alphabetically, which includes values for the mean, standard deviation, maximum, and minimum value for the whole sample.

The attributes are grouped into functional categories, as described above in Section III. We present this information in the order listed below:

Variable Definitions and Descriptive Statistics:

1. Modeling and Analytical Power
2. Speed and Capacity
3. Presentation and Output Power
4. Data Manipulation Power and Ease
5. Network Externality Effects:
    a. Size of Installed Bases of Software and PCs
    b. Cross-Platform Compatibility
    c. Database Compatibility and Access
    d. Operating System Required
    e. Lotus 1-2-3 Compatibility
    f. Data Exchange
6. Make Effects
7. Dependent Variable - Product Price
8. Other Attributes
9. Complete Descriptive Statistics for All Variables

1. Modeling and Analytical Power Variables

Table 16: Variable Definitions -- Modeling and Analytical Power

Modeling Power Variables	
Variable	*Description*
CELLINKF	CELLINKF equals one if the spreadsheet supports formulas which reference links to other files. Note that some spreadsheet support cells which contain a link and nothing else (no formula other than the link); this does not qualify for a one in CELLINKF. To qualify for CELLINKF the program must support links to external spreadsheets within the context of a regular formula.
CELLINK	CELLINK equals one if the spreadsheets supports linking of external worksheets.
NUMFUNCT	The number of functions supported by the worksheet.
PROGRAM	PROGRAM equals one if the spreadsheet supports programmable macros.
LEARN	LEARN equals one if the spreadsheet supports recorded keystroke macros.
VERSATIL	A score given by NSTL on this product's versatility

Figure 5: Implementation of Modeling Power Variables By Year

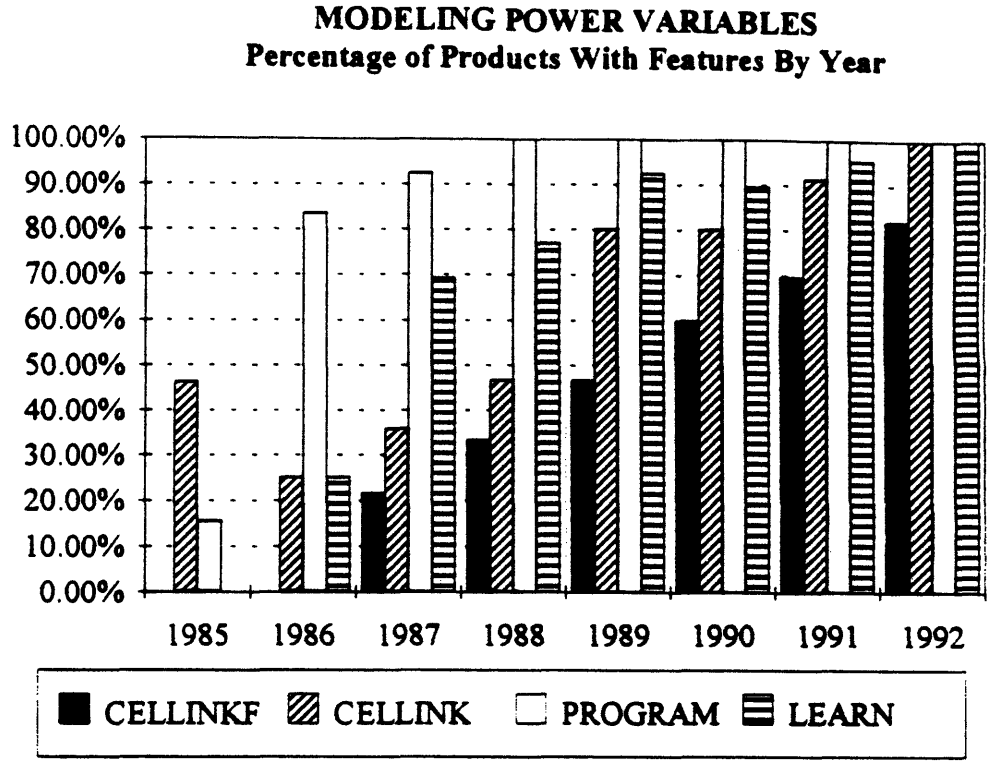

Table 17: Mean Values of Modeling and Analytical Power Variables By Year

Year	Sample Size	Cellinkf	Cellink	Program	Learn	Numfunct
1985	13	0.00%	46.15%	15.38%	0.00%	42.00
1986	12	0.00%	25.00%	83.33%	25.00%	90.00
1987	14	21.43%	35.71%	92.31%	69.23%	100.83
1988	15	33.33%	46.67%	100.00%	76.92%	97.43
1989	17	46.67%	80.00%	100.00%	92.31%	98.50
1990	20	60.00%	80.00%	100.00%	89.47%	106.56
1991	23	69.57%	91.30%	100.00%	95.24%	132.23
1992	11	81.82%	100.00%	100.00%	100.00%	156.64
All Years	125	43.20%	66.40%	88.80%	73.60%	113.69

Notes: NumFunct was available for 60 observations in this sample.

2. Speed and Capacity Variables

Table 18: Variable Definitions – Speed and Capacity

Speed and Capacity Variables	
Variable	***Description***
MAXROW	The maximum number of rows allowed by the spreadsheet.
MAXCOL	The maximum number of columns allowed by the spreadsheet.
NUMCELLS	NUMCELLS equals a value calculated as follows: (MaxRow * MaxCol). This is a measure of the total spreadsheet size supported by the program.
LN_NCELL	LN_NCELL equals a value calculated as follows: Natural Log(NUMCELLS).
RAMREQ	The amount of RAM required by the spreadsheet in kilobytes.
LN_RAM	Natural log of RAMREQ.
MINCALC	MINCALC equals one if the spreadsheet supports minimal recalc, a feature which enables the spreadsheet to recalculate only cells which need to be recalculated, rather than recalculating the entire spreadsheet when changes are made.
BACKCALC	BACKCALC equals one if the spreadsheet supports background recalculation.
AUTOCALC	AUTOCALC equals one if the spreadsheet supports automatic recalculation when a change is made to the worksheet.
RECALC	Sum of MINCALC and BACKCALC.
PERFORM	A score given by NSTL on this product's performance
POWER	A score given by NSTL on this product's overall power

NOTE: Information on Perform and Power was available for 42 and 47 products respectively in our sample.

Figure 6: Implementation of Speed and Capacity Variables By Year

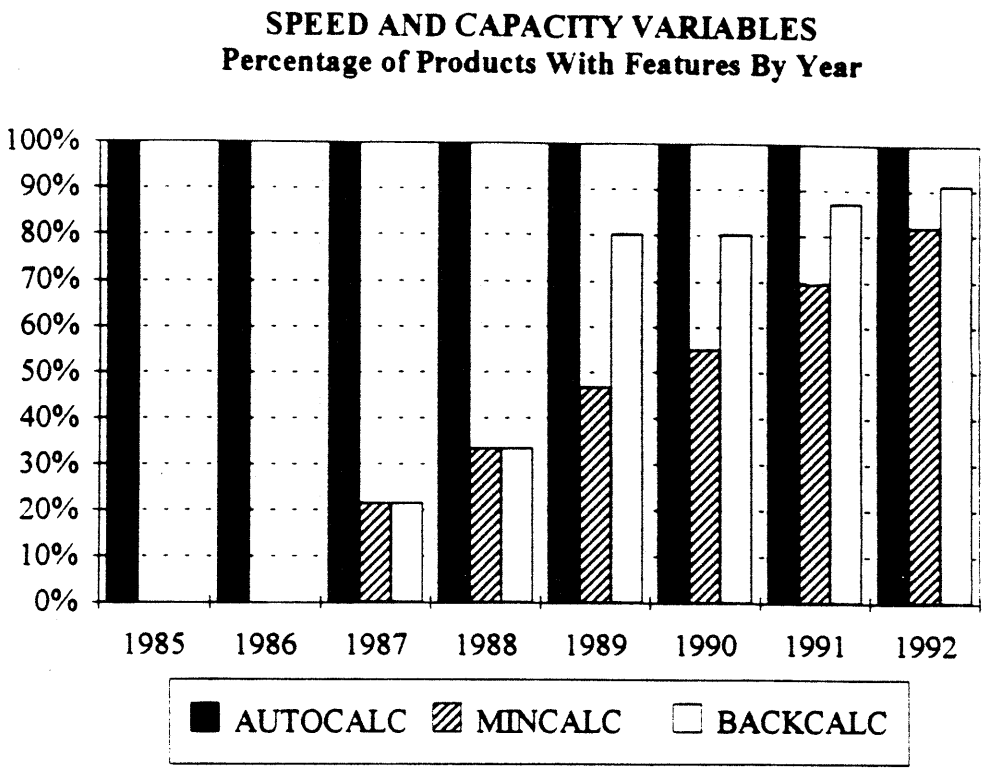

Table 19: Mean Values of Speed and Capacity Variables By Year

Year	Sample Size	Maxrow	Maxcol	Numcells (in 000's)	Ramreq (in KB)	Autocalc	Mincalc	Backcalc
1985	13	2,660.92	923.92	104.61	162.08	100.00%	0.00%	0.00%
1986	12	7,280.58	275.33	1,016.56	203.67	100.00%	0.00%	0.00%
1987	14	11,358.36	3,783.00	5,066.33	374.86	100.00%	21.43%	21.43%
1988	15	10,191.53	2,522.33	3,452.25	445.60	100.00%	33.33%	33.33%
1989	17	11,147.27	4,639.93	4,773.26	810.67	100.00%	46.67%	80.00%
1990	20	14,094.85	6,758.05	7,518.29	1,132.80	100.00%	55.00%	80.00%
1991	23	14,314.87	7,323.52	8,276.09	1,271.65	100.00%	69.57%	86.96%
1992	11	14,478.36	6,167.00	7,660.06	1,974.00	100.00%	81.82%	90.91%
Overall	125	11,233.82	4,318.30	13,392.23	831.40	100.00%	54.40%	42.40%

3. Presentation and Output Variables

Table 20: Variable Definitions -- Presentation and Output

Presentation and Output Variables	
Variable	*Description*
CHARTING	CHARTING equals one if the spreadsheet includes facilities to make graphs of the data.
EMBEDCHT	EMBEDCHT equals one if the spreadsheet supports embedded charts (i.e. the ability to print datasheets and graphs on the same page.)
FONT_SUP	FONT_SUP equals one if the spreadsheet supports more than one font simultaneously on a worksheet or a graph.
PRNTPREV	PRNTPREV equals one if the spreadsheet can show an on-screen print preview.
WYSIWYG	WYSIWYG equals one if the spreadsheet supports a WYSIWYG editing screen (i.e. the spreadsheet editing window shows the spreadsheet attributes just as they will print.)

Figure 7: Implementation of Presentation and Output Variables By Year

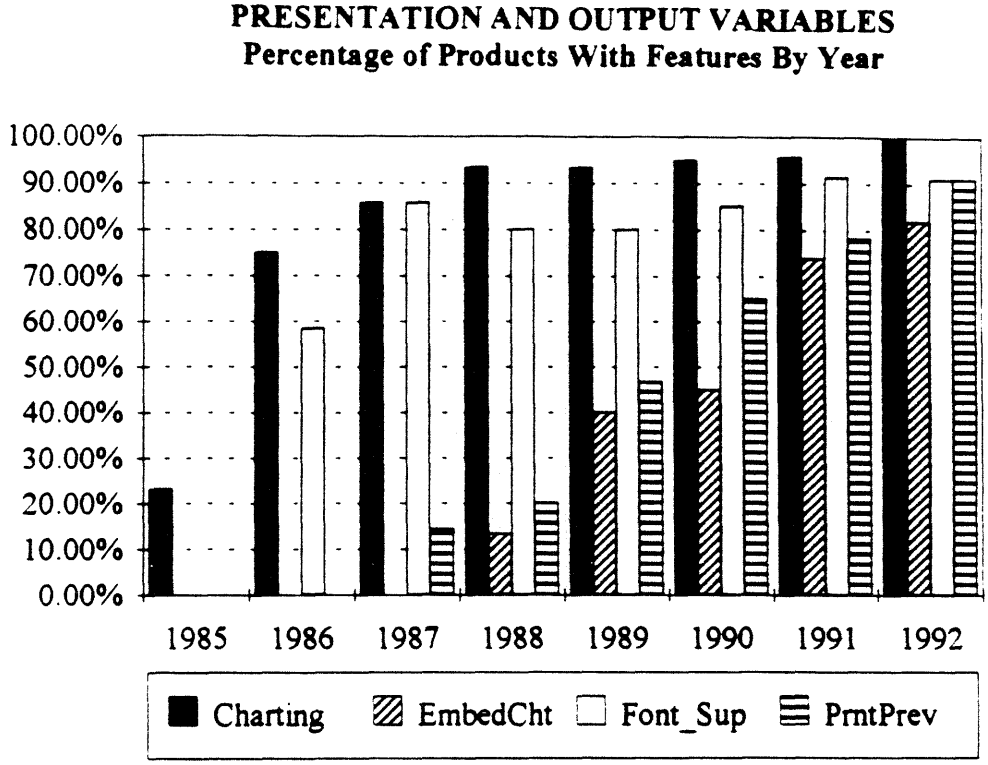

Table 21: Mean of Presentation and Output Variables By Year

Year	Sample Size	Charting	EmbedCht	Font_Sup	PrntPrev
1985	13	23.08%	0.00%	0.00%	0.00%
1986	12	75.00%	0.00%	58.33%	0.00%
1987	14	85.71%	0.00%	85.71%	14.29%
1988	15	93.33%	13.33%	80.00%	20.00%
1989	17	93.33%	40.00%	80.00%	46.67%
1990	20	95.00%	45.00%	85.00%	65.00%
1991	23	95.65%	73.91%	91.30%	78.26%
1992	11	100.00%	81.82%	90.91%	90.91%
All Years	125	84.80%	34.40%	74.40%	44.00%

4. Data Manipulation Power and Ease Variables

Table 22: Variable Definitions -- Data Manipulation Power and Ease

Data Manipulation Power and Ease	
Variable	***Description***
MOUSE	MOUSE equals one if the spreadsheet supports at least three of the following mouse shortcuts: Pull-down menus, Drag-n-Drop editing, Speed Formatting, Speed Filling, and Icon/Button Bars
SORTCOL	SORTCOL equals one if the program supports sorting by columns (rather than rows.)
SRCHRPL	SRCHRPL equals one if the program supports global search and replace through cell contents.
LEARNING	A score given by NSTL on this product's ease of learning
OVERUSE	A score given by NSTL on this product's overall useability
USE	A score given by NSTL on this product's ease of use
WYSIWYG	WYSIWYG equals one if the spreadsheet supports a WYSIWYG editing screen (i.e. the spreadsheet editing window shows the spreadsheet attributes just as they will print.)

NOTE: Information on Learning and Overuse was available for only 47 products in our sample; data for Use was available for 39 products in our sample.

Figure 8: Implementation of Data Manipulation Variables By Year

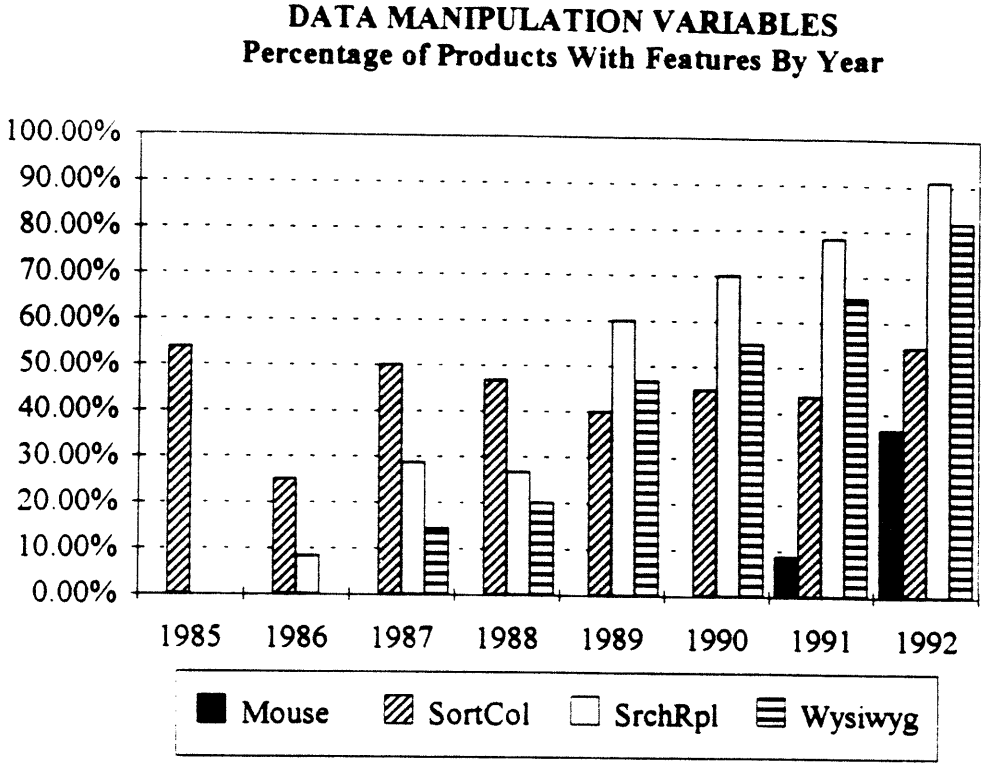

Table 23: Mean of Data Manipulation Power and Ease Variables By Year

Year	Sample Size	Mouse	SortCol	SrchRpl	Wysiwyg
1985	13	0.00%	53.85%	0.00%	0.00%
1986	12	0.00%	25.00%	8.33%	0.00%
1987	14	0.00%	50.00%	28.57%	14.29%
1988	15	0.00%	46.67%	26.67%	20.00%
1989	17	0.00%	40.00%	60.00%	46.67%
1990	20	0.00%	45.00%	70.00%	55.00%
1991	23	8.70%	43.48%	78.26%	65.22%
1992	11	36.36%	54.55%	90.91%	81.82%
All Years	125	4.80%	45.60%	49.60%	39.20%

5. Network Externality Variables

a. Size of Installed Base of Software and PCs

Table 24: Variable Definitions -- Size of Installed Bases

Network Externality Variables -- Size of Installed Bases	
Variable	***Description***
INSTLBAS	Installed base of the spreadsheet product (all versions).
LNINBASL	Natural log of INSTLBAS
IBLOTUS	Installed base of all spreadsheets capable of reading and writing Lotus 1-2-3 files.
PCINSTLD	Installed base of personal computers (all makes, both IBM compatible and Macintosh and other platforms).

Note: Mean values for these variables would be meaningless. Hence, they are not provided here.

b. Cross-Platform Compatibility

Table 25: Variable Definitions -- Cross-Platform Compatibility

Cross-Platform Compatibility	
Variable	*Description*
OP_MAC	OP_MAC equals one if this spreadsheet is also offered on the Macintosh platform (assuming the current product is not a Macintosh product).
OP_OS2	OP_OS2 equals one if this spreadsheet is also offered on the IBM OS/2 platform (assuming the current product is not a OS/2 product).
OP_DOS	OP_DOS equals one if this spreadsheet is also offered on the MS-DOS platform (assuming the current product is not an MS-DOS product).
OP_WIN	OP_WIN equals one if this spreadsheet is also offered on the MS Windows platform (assuming the current product is not a Windows product).
OTHEROS	OTHEROS is the sum of OP_MAC, OP_OS2, OP_DOS and OP_WIN.

Figure 9: Implementation of Cross-Platform Compatibility By Year

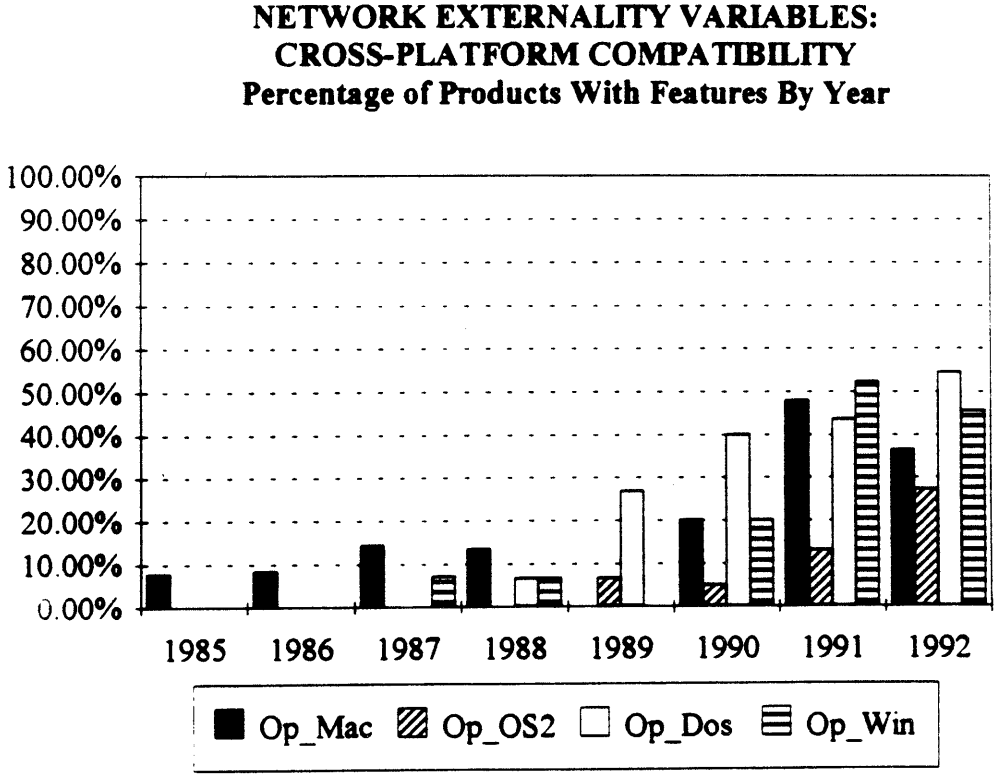

Table 26: Mean of Cross-Platform Compatibility Variables By Year

Year	Sample Size	Op_Mac	Op_OS2	Op_Dos	Op_Win
1985	13	7.69%	0.00%	0.00%	0.00%
1986	12	8.33%	0.00%	0.00%	0.00%
1987	14	14.29%	0.00%	0.00%	7.14%
1988	15	13.33%	0.00%	6.67%	6.67%
1989	17	0.00%	6.67%	26.67%	0.00%
1990	20	20.00%	5.00%	40.00%	20.00%
1991	23	47.83%	13.04%	43.48%	52.17%
1992	11	36.36%	27.27%	54.55%	45.45%
All Years	125	20.80%	23.20%	6.40%	19.20%

c. Database Compatibility and Access

Table 27: Variable Definitions -- Database Compatibility and Access

Database Compatibility and Access	
Variable	*Description*
EXTLINK	EXTLINK equals one if the spreadsheet supports direct links to external data sources (such as mainframes or database servers).
PARADOX	PARADOX equals one if the spreadsheet can read or import Borland Paradox database files
SQL	SQL equals one if the program supports direct links to an SQL database server.
DBASE	DBASE equals one if the spreadsheet can read or directly import dBase files.
DB_COMP	Sum of DBASE, SQL, and PARADOX.

Figure 10: Implementation of Database Compatibility and Access By Year

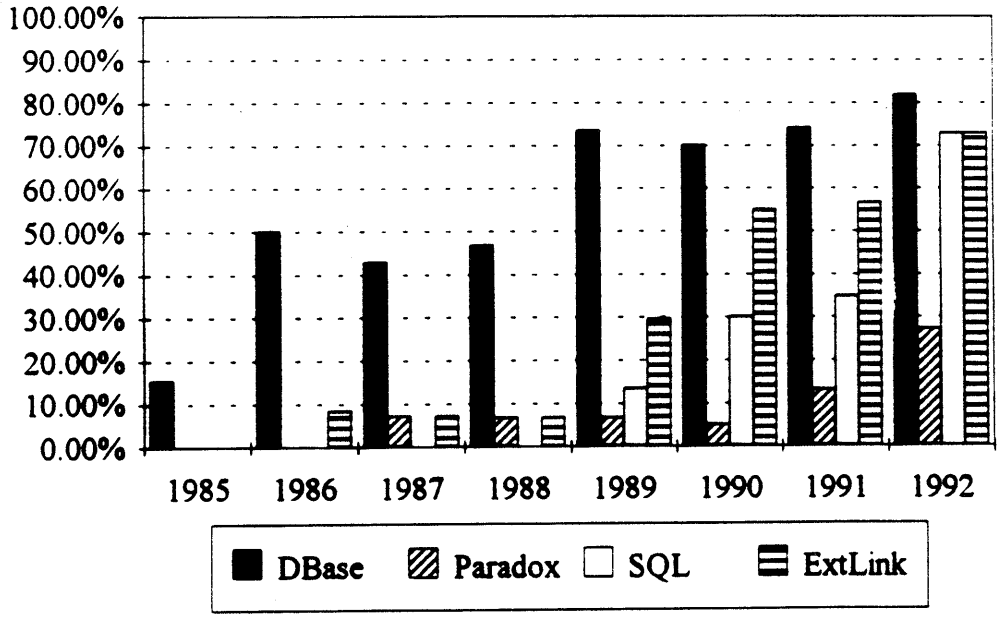

Table 28: Mean of Database Compatibility and Access Variables By Year

Year	Sample Size	DBase	Paradox	SQL	ExtLink
1985	13	15.38%	0.00%	0.00%	0.00%
1986	12	50.00%	0.00%	0.00%	8.33%
1987	14	42.86%	7.14%	0.00%	7.14%
1988	15	46.67%	6.67%	0.00%	6.67%
1989	17	73.33%	6.67%	13.33%	29.41%
1990	20	70.00%	5.00%	30.00%	55.00%
1991	23	73.91%	13.04%	34.78%	56.52%
1992	11	81.82%	27.27%	72.73%	72.73%
All Years	125	59.20%	8.00%	19.20%	32.00%

d. Operating System Required

Table 29: Variable Definitions -- Operating System Required

Operating System Required	
Variable	*Description*
OS2	OS2 equals one if the program being reported on is an OS/2 program.
OSMAC	OSMAC equals one if the program being reported on is a Macintosh program.
OSWIN	OSWIN equals one if the program being reported on is a Microsoft Windows program. If all of OS2, OSMAC and OSWIN are zero, the program is a DOS program.

Figure 11: Distribution of Products By Operating System By Year

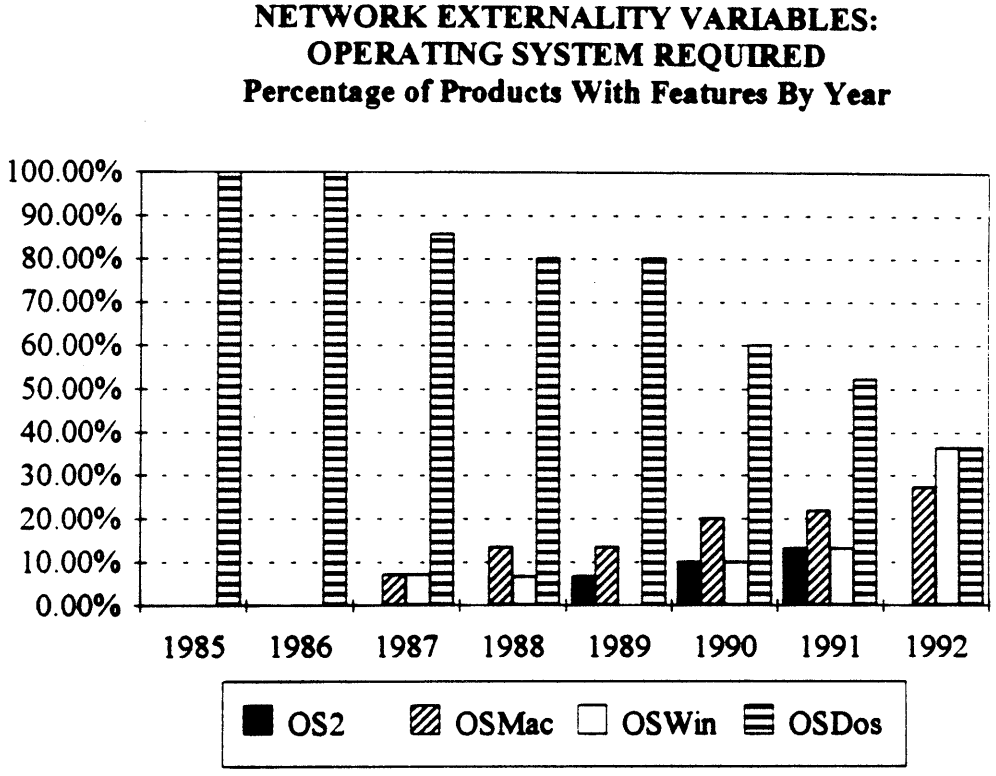

Table 30: Mean of Operating System Required Variables By Year

Year	Sample Size	OS2	OSMac	OSWin	OSDos
1985	13	0.00%	0.00%	0.00%	100.00%
1986	12	0.00%	0.00%	0.00%	100.00%
1987	14	0.00%	7.14%	7.14%	85.71%
1988	15	0.00%	13.33%	6.67%	80.00%
1989	17	6.67%	13.33%	0.00%	80.00%
1990	20	10.00%	20.00%	10.00%	60.00%
1991	23	13.04%	21.74%	13.04%	52.17%
1992	11	0.00%	27.27%	36.36%	36.36%
All Years	125	4.80%	14.40%	9.60%	71.20%

e. Lotus 1-2-3 Compatibility

Table 31: Variable Definitions – Lotus 1-2-3 Compatibility

Lotus 1-2-3 Compatibility	
Variable	***Description***
LOTFILE	LOTFILE equals one if the program can read or import and write or export Lotus 1-2-3 files (any version).
LOTMAC	LOTMAC equals one if the program can execute or import Lotus 1-2-3 macros.
LOTMENU	LOTMENU equals one if the program supports a menu structure that is largely the same as the Lotus 1-2-3 style menus.
LOTCOMP	Sum of LOTFILE, LOTMAC, and LOTMENU.

Figure 12: Implementation of Lotus 1-2-3 Compatibility By Year

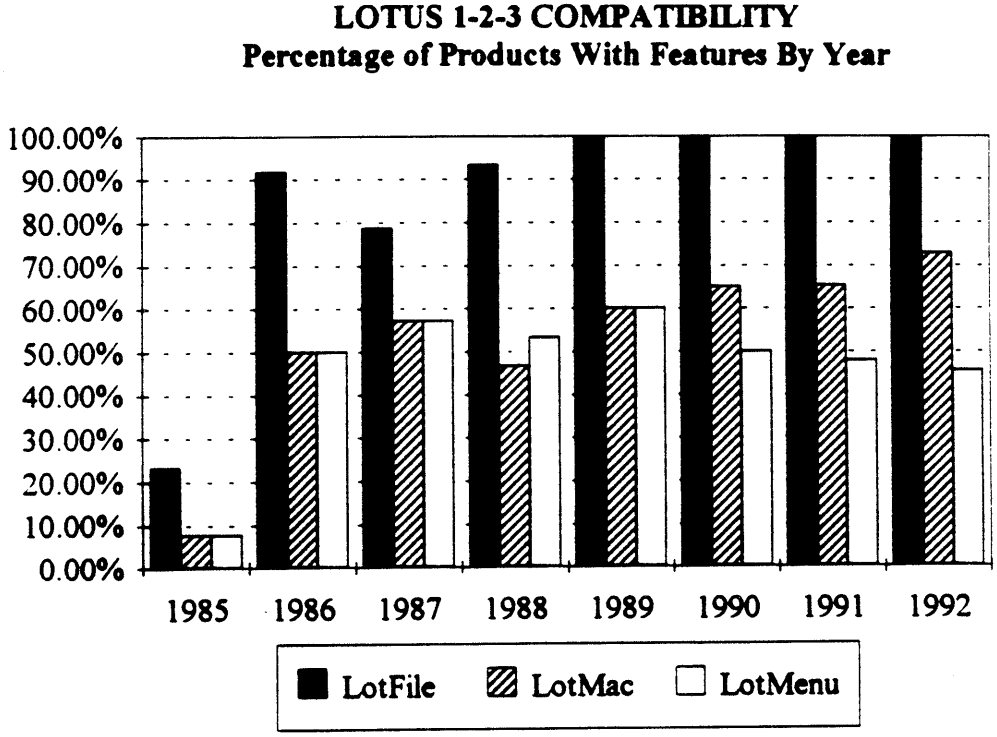

Table 32: Mean of Lotus 1-2-3 Compatibility By Year

Year	Sample Size	LotFile	LotMac	LotMenu
1985	13	23.08%	7.69%	7.69%
1986	12	91.67%	50.00%	50.00%
1987	14	78.57%	57.14%	57.14%
1988	15	93.33%	46.67%	53.33%
1989	17	100.00%	60.00%	60.00%
1990	20	100.00%	65.00%	50.00%
1991	23	100.00%	65.22%	47.83%
1992	11	100.00%	72.73%	45.45%
All Years	125	88.00%	54.40%	46.40%

f. Data Exchange

Table 33: Variable Definitions – Data Exchange

Data Exchange	
Variable	*Description*
DDE	DDE equals one if the spreadsheet supports either the Microsoft Windows DDE (Dynamic Data Exchange) mechanism or the Macintosh Publish/Subscribe data exchange mechanism. This feature enhances the spreadsheet's interoperability with other programs under the same environment.
LAN	LAN equals one if the spreadsheet supports file locking--a key feature to making the program work securely on Local Area Networks.
LOTFILE	LOTFILE equals one if the program can read or import and write or export Lotus 1-2-3 files (any version).

Figure 13: Implementation of Data Exchange By Year

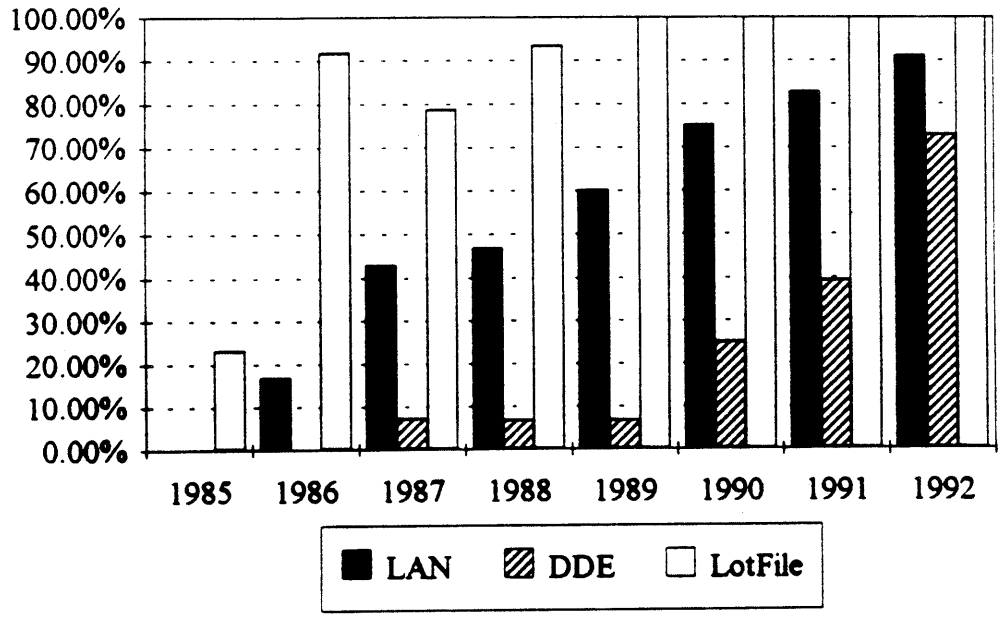

Table 34: Mean of Data Exchange Variables By Year

Year	Sample Size	LAN	DDE	LotFile
1985	13	0.00%	0.00%	23.08%
1986	12	16.67%	0.00%	91.67%
1987	14	42.86%	7.14%	78.57%
1988	15	46.67%	6.67%	93.33%
1989	17	60.00%	6.67%	100.00%
1990	20	75.00%	25.00%	100.00%
1991	23	82.61%	39.13%	100.00%
1992	11	90.91%	72.73%	100.00%
All Years	125	56.00%	20.80%	88.00%

6. Make Effect Variables

Table 35: Variable Definitions – Make Effect

Make Effect Variables	
Variable	*Description*
MFR_BORL	MFR_BORL equals one if the manufacturer of the spreadsheet is Borland
MFR_LOT	MFR_LOT equals one if the manufacturer of the spreadsheet is Lotus Development Corp.
MFR_MS	MFR_MS equals one if the manufacturer of the spreadsheet is Microsoft.
MFR_CA	MFR_CA equals one if the manufacturer of the spreadsheet is Computer Associates.

Figure 14: Distribution of Products By Manufacturers By Year

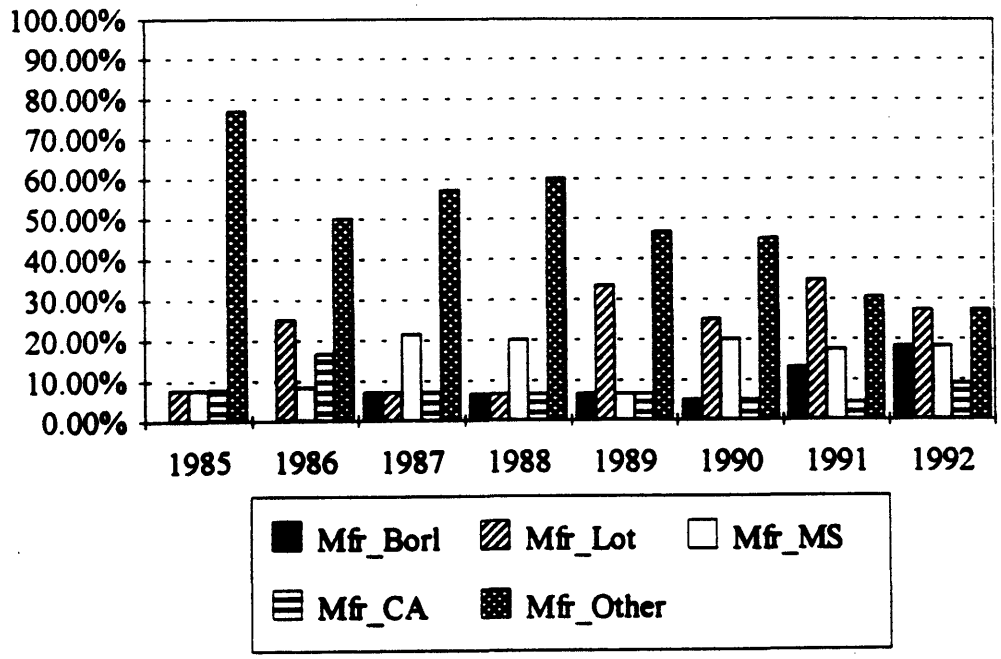

Table 36: Mean of Make Effects By Year

Year	Sample Size	Mfr_Borl	Mfr_Lot	Mfr_MS	Mfr_CA	Mfr_Other
1985	13	0.00%	7.69%	7.69%	7.69%	76.92%
1986	12	0.00%	25.00%	8.33%	16.67%	50.00%
1987	14	7.14%	7.14%	21.43%	7.14%	57.14%
1988	15	6.67%	6.67%	20.00%	6.67%	60.00%
1989	17	6.67%	33.33%	6.67%	6.67%	46.67%
1990	20	5.00%	25.00%	20.00%	5.00%	45.00%
1991	23	13.04%	34.78%	17.39%	4.35%	30.43%
1992	11	18.18%	27.27%	18.18%	9.09%	27.27%
All Years	125	7.20%	21.60%	16.80%	7.20%	47.20%

7. Dependent Variable -- Levels of Product Price

Table 37: Variable Definitions -- Dependent Variable

Levels of Product Price	
Variable	***Description***
LISTP	Nominal list price of the spreadsheet product. DataQuest data was chosen first if multiple data sources were available.
MINLISTP	The minimum nominal list price of the spreadsheet product when various data sources gave slightly different prices.
MINFACTP	The minimum factory average selling price when various data sources gave slightly different prices.
R_LISTP	The real list price of the product (in 1987 dollars).
RMINLP	The minimum of the real list price when various data sources gave slightly different prices.
RMINFCTP	The minimum of the real average factory selling price.
LNRLISTP	The natural log of R_LISTP
LNRMINLP	The natural log of RMINLP
LNRFACTP	The natural log of RMINFCTP

Figure 15: Nominal and Real Average Product Price By Year

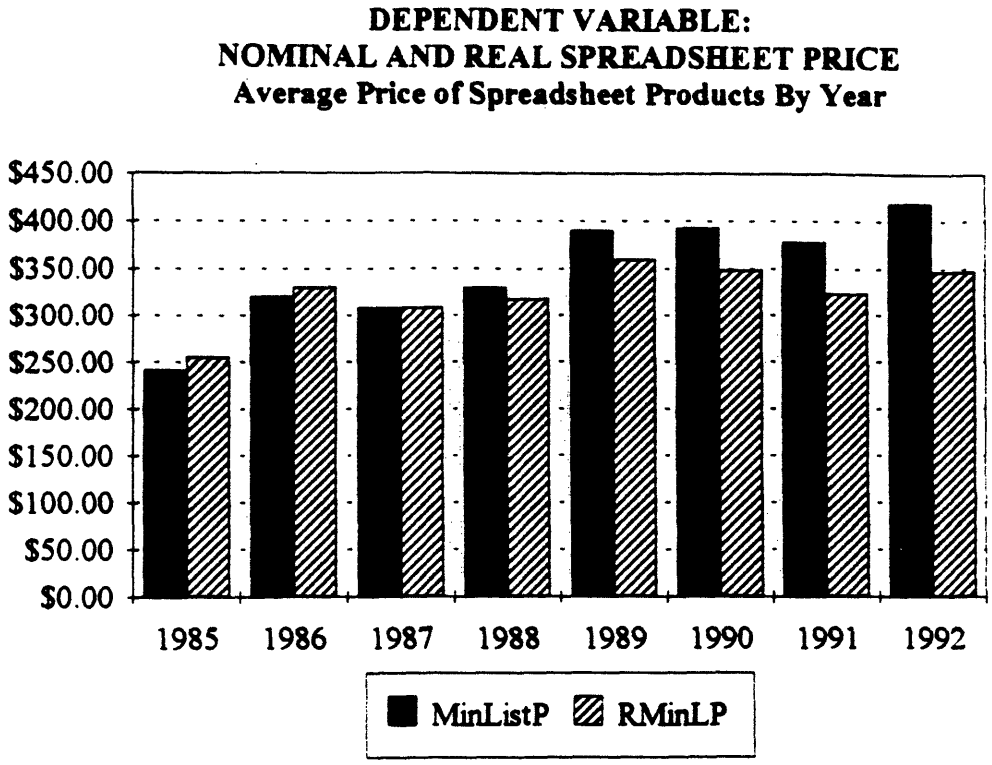

Table 38: Mean of Nominal and Real Spreadsheet Prices By Year

Year	Sample Size	MinListP	RMinLP
1985	13	$240.15	$254.49
1986	12	$319.41	$329.58
1987	14	$307.43	$307.43
1988	15	$328.90	$316.69
1989	17	$389.46	$359.23
1990	20	$392.25	$347.51
1991	23	$377.08	$322.61
1992	11	$418.45	$346.17
All Years	125	$351.56	$324.90

8. Other Attributes

Table 39: Variable Definitions -- Other Attributes

Other Variables	
Variable	***Description***
T85 thru T92	Dummy variables for the year.
EOR_UNIT	The number of units sold for this spreadsheet in this year (priority given to DataQuest data when available).
LNUNITS	The natural log of EOR_UNIT
MKT_SHR	The market share held by this product in this year
MINMKTSH	The minimum of market share when various data sources gave slightly different market shares.

Note: Mean values for these variables would be meaningless. Hence, they are not provided here.

Table 40: Descriptive Statistics For All Variables

Variable	N	Mean	STD	Maximum	Minimum
AutoCalc	125	1.000	0.000	1.00	0.00
BackCalc	125	0.424	0.496	1.00	0.00
Cellink	125	0.664	0.474	1.00	0.00
CellinkF	125	0.432		1.00	0.00
Charting	125	0.848	0.360	1.00	0.00
DBase	125	0.592	0.493	1.00	0.00
DDE	125	0.208	0.408	1.00	0.00
EmbedCht	125	0.344	0.477	1.00	0.00
EorUnit	79	225,048.19	305,246.33	4,876,307.00	2,000.00
ExtLink	125	0.319	0.468	1.00	0.00
FontSup	125	0.744	0.438	1.00	0.00
IBLotus	100	7,355,530.77	5,269,507.59	0.16895*E08	260,000.00
IBLScal (in100,000's)	100	735.55	526.951	1,689.48	26.00
IBScale (in 100,000's)	100	104.52	217.192	1,007.21	0.00
InstlBas	100	1,045,165.51	2,171,924.48	0.10072*E08	1.00
LAN	125	0.560	0.498	1.00	0.00
Learn	125	0.736	0.443	1.00	0.00
Learning	39	7.754	1.399	9.60	4.40
ListP	125	362.160	167.660	795.00	49.95
ListPChg	76	-2.887	114.274	300.00	-545.00
LnInBasL	100	6.126	5.988	16.125	0.00
LnNCell	125	15.014	2.669	20.794	9.493
LnRAM	125	6.209	0.975	8.318	4.159
LnRFactP	72	4.787	0.515	5.730	3.363
LnRListP	125	5.664	0.611	6.678	3.755
LnRMinLP	125	5.633	0.617	6.423	3.755
LnUnits	79	11.210	1.705	14.152	7.601
LotComp	125	1.888	1.101	3.00	0.00
LotFile	125	0.880	0.326	1.00	0.00
LotMac	125	0.544	0.500	1.00	0.00
LotMenu	125	0.464	0.501	1.00	0.00
MaxCol	125	4381.30	10,658.18	32,768.00	52.00
MaxRow	125	11,233.82	8,998.82	32,768.00	254.00

Variable	N	Mean	STD	Maximum	Minimum
Mfr_Borl	125	0.072	0.260	1.00	0.00
Mfr_CA	125	0.072	0.260	1.00	0.00
Mfr_Lot	125	0.216	0.413	1.00	0.00
Mfr_MS	125	0.168	0.375	1.00	0.00
MinCalc	125	0.544	0.500	1.00	0.00
MinFactP	72	148.763	71.191	347.50	30.00
MinListP	125	351.561	161.465	695.00	49.95
MinMktSh	77	0.075	0.118	0.62	0.00
MinPChg	76	-3.282	85.206	245.00	-346.00
MktShr	77	0.095	0.136	0.62	0.00
Mouse	125	0.048	0.215	1.00	0.00
NumFunct	60	117.233	55.846	339.00	42.00
OP_DOS	125	0.064	0.246	1.00	0.00
OP_Mac	125	0.208	0.408	1.00	0.00
OP_OS2	125	0.232	0.424	1.00	0.00
OP_Win	125	0.192	0.395	1.00	0.00
OS2	125	0.048	0.215	1.00	0.00
OSMac	125	0.144	0.353	1.00	0.00
OSWin	125	0.096	0.296	1.00	0.00
OtherOS	125	0.832	1.236	4.00	0.00
Overall	47	7.181	0.986	8.90	4.80
OverUse	47	7.613	1.403	9.70	4.70
Paradox	125	0.080	0.272	1.00	0.00
PCInstld (in 000's)	125	33,965.732	13,162.540	55,384.50	13,092.50
PCShipd (in 000's)	125	6,424.816	1,077.066	8,295.00	4,750.00
Perform	47	6.115	1.649	9.50	2.10
Power	42	6.552	1.040	8.20	4.00
PrntPrev	125	0.440	0.498	1.00	0.00
Program	125	0.888	0.317	1.00	0.00
RAMReq (in KB)	125	831.400	1,010.927	4,096.00	64.00
ReCalc	125	0.968	0.870	2.00	1.00
RFactPCh	45	-4.554	96.512	399.66	-271.74
RListP	125	334.820	153.575	795.00	42.73
RListPCh	74	-15.811	108.470	284.26	-554.29
RMinFctP	76	128.286	70.700	307.87	0.00
RMinLP	125	324.904	145.977	615.73	42.73
SortCol	125	0.456	0.500	1.00	0.00
SQL	125	0.192	0.395	1.00	0.00
SrchRpl	125	0.496	0.502	1.00	0.00
T85	125	0.104	0.306	1.00	0.00

Variable	N	Mean	STD	Maximum	Minimum
T86	125	0.096	0.296	1.00	0.00
T87	125	0.112	0.317	1.00	0.00
T88	125	0.120	0.326	1.00	0.00
T89	125	0.136	0.344	1.00	0.00
T90	125	0.160	0.368	1.00	0.00
T91	125	0.184	0.389	1.00	0.00
T92	125	0.088	0.284	1.00	0.00
UnitsChg	52	-6,450.288	282,774.305	635,000.00	-1,388,000.00
Use	39	7.621	1.516	9.60	4.50
Versatil	47	7.302	1.065	9.20	4.50
Wysiwyg	125	0.392	0.490	1.00	0.00

APPENDIX B: RESULTS FROM GANDAL'S MODEL

During the course of our research, we became familiar with a recent working paper by Neil Gandal (1992)[58]. Gandal examined spreadsheet products over the 1986 to 1991 period that operate on the DOS, Windows, and OS/2 operating system platforms. Using data on product attributes, Gandal estimated a hedonic price equation to construct quality-adjusted price indexes for spreadsheets. Gandal also used this technique to document the presence of network externality effects in this market. Gandal concluded that consumers were willing to pay a premium for spreadsheet products that offer file compatibility with Lotus 1-2-3, external links to databases, and local area network (LAN) connectivity. Additionally, Gandal found that the quality-adjusted price of spreadsheet software has declined by roughly 15% per year over the period.

In this appendix, we apply Gandal's preferred model to the relevant subset of data collected for this paper.

Gandal's variables are defined in Tables 41 and 42 below:

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[58] Neil Gandal [1992], "Hedonic Price Indexes for Spreadsheets and an Empirical Test of the Network Externalities Hypothesis," August 17, 1992, mimeo paper.

Table 41: Description of Dummy Variables Used in Gandal's Study

VARIABLE NAME	CONDITIONS TO TURN VALUE FROM ZERO TO ONE	OTHER VALUES
EXTDAT	Provides links to external databases	
GRAPHS	Can create pie, bar, and line graphs	
LANCOM	Offers a LAN version	
LEARN	Macros can be recorded as keystrokes are pressed	
LINKING	Values in several worksheets can be updated at the same time	
LOCOMP	Can read and write files with the Lotus (WKS, WK1) format	
LOTUS	Manufactured by Lotus Development Corporation	
PRESENT	If worksheets and graphs can be printed on the same page OR if multiple printing fonts are available	If both features are available, PRESENT takes on the value two
PRINT	Three or more of the following five advanced print functions are possible: sideways, background, preview mode, PostScript support, and printing of non-contiguous worksheet ranges	
PROGRAM	Macros can be written using programming-like statements	
SORTING	Can sort a group of data observations on at least two levels	
WINDOW	Maximum number of windows on-screen simultaneously is between two and fifteen	If maximum is sixteen or more, WINDOW is equal to two

Table 42: Description of Continuous Variables Used in Gandal's Study

VARIABLE NAME	DEFINITION
LMINRC	Natural log of MINRC
LPRICE	Natural log of PRICE
MINRC	Minimum of the maximum number of rows and columns that the spreadsheet can handle
PRICE	List price for a single copy of the program

We collected data on these variables, adhering as closely as we could to the definitions provided by Gandal in his paper. We first excluded Macintosh-based products from our sample to obtain comparable results. This resulted in a sample of 86 products to examine over the 1986 to 1991 period considered by Gandal. Hereafter, this sub-sample of 86 products is referred to as the "Thesis Sub-sample." Table X below displays the comparative descriptive statistics on each sample.

Table 43: Comparative Descriptive Statistics

	Mean		Standard Deviation	
VARIABLE NAME	Gandal Sample (N=91)	Thesis Sub-Sample (N=86)	Gandal Sample (N=91)	Thesis Sub-Sample (N=86)
PRICE	274.40	366.54	205.80	180.43
LPRICE	5.25	5.73	0.94	0.66
MINRC	285.00	3504.81	261.50	9585.85
LMINRC	5.30	6.08	0.89	1.51
EXTDAT	0.24	0.26	0.43	0.44
GRAPHS	0.65	0.90	0.48	0.31
LANCOM	0.51	0.59	0.50	0.50
LINKING	0.59	0.58	0.49	0.50
LOCOMP	0.74	0.95	0.44	0.21
LOTMAC	--	0.65	--	0.48
LOTMENU	--	0.59	--	0.49
LOTUS	0.13	0.26	0.34	0.44
LEARN	0.67	0.77	0.47	0.42
PRESENT	0.34	1.06	0.70	0.69
PRINT	0.19	0.43	0.39	0.50
PROGRAM	0.80	0.97	0.40	0.18
RECALC	0.96	1.00	0.21	0.00
SORTING	0.67	0.92	0.47	0.28
WINDOW	0.86	0.91	0.66	0.86

These descriptive statistics highlight several differences between the two product samples under consideration. First, our thesis sub-sample mean for PRICE is almost $100 higher than the mean obtained by Gandal. This is likely due to the exclusion of shareware products in our sample. Shareware products tend to be significantly less expensive than

business-class spreadsheet products. Second, our product sample offers a higher proportion of what Gandal called "advanced features."[59] For example, 97% of our sample supports the ability to write programmable macros compared to 80% for Gandal's sample. This is true also for PRINT, PRESENT, LEARN, and LANCOM. Third, our sample included several products that offered a row-column matrix size of 32,768 by 32,768. These products are Professional Plan by Software Publishing Company and Wingz by Informix. Based on the range of values that Gandal obtained for the variables MINRC (minimum of 25, maximum of 1024), these products could not have been included in Gandal's sample. The mean value that we obtain for MINRC is significantly higher than that for the Gandal sample for this reason.

Gandal's preferred model expresses the natural log of list price as a function of product attributes and time dummy variables:

$$(7)\quad \begin{aligned} LNPRICE = {} & \beta_0 + \beta_1*TIME87 + \beta_2*TIME88 + \beta_3*TIME89 \\ & + \beta_4*TIME90 + \beta_5*TIME91 + \beta_6*LMINRC + \beta_7*LOTUS \\ & + \beta_8*GRAPHS + \beta_9*WINDOW + \beta_{10}*LOCOMP + \beta_{11}*EXTDAT \\ & + \beta_{12}*LANCOM + \beta_{13}*LINKING \end{aligned}$$

The table below displays the results of the regressions run on our sample versus Gandal's results:

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[59] Neil Gandal [1992], "Hedonic Price Indexes for Spreadsheets and an Empirical Test of the Network Externalities Hypothesis," August 17, 1992, mimeo paper, p. 7. Gandal considered EXTDAT, PROGRAM, LEARN, LANCOM, PRINT, and PRESENT to be advanced features.

Table 44: Results of Gandal's Preferred Regression on Thesis Sub-Sample

	Gandal Sample		Thesis Sub-Sample	
VARIABLE	Coefficient	T-Stat	Coefficient	T-Stat
CONSTANT	3.76	12.31	5.57	14.85
TIME87	-0.06	-0.38	-0.10	-0.50
TIME88	-0.44	-2.67	-0.12	-0.56
TIME89	-0.70	-4.20	-0.13	-0.60
TIME90	-0.79	-4.90	-0.14	-0.66
TIME91	-0.85	-5.30	-0.25	-1.11
EXTDAT	0.55	4.05	-0.43	-2.81
GRAPHS	0.46	3.51	0.43	2.04
LANCOM	0.21	1.65	0.50	2.96
LINKING	0.21	1.91	-0.32	-1.57
LMINRC	0.11	1.59	-0.10	-2.35
LOCOMP	0.72	5.28	0.00	-0.01
LOTUS	0.56	4.36	0.74	5.25
WINDOW	0.17	2.14	0.40	3.64
N	91		86	
S.E. of Regression	0.385		0.494	
R-Squared	0.857		0.521	
Adjusted R-Squared	0.833		0.435	

When the regressions are run, we find that this model does not explain the thesis sub-sample as well as it explains Gandal's. Compared to Gandal's adjusted R-squared values of 0.833 and standard error of 0.385, our regression results in an adjusted R-squared of only about 0.435 with a much higher standard error of 0.494. We find that there are positive, significant premiums associated with GRAPHS, LANCOM, LOTUS, and WINDOW. These values are roughly in line with those estimated by Gandal.

However, the coefficient estimates we obtained for several of Gandal's variables are in the wrong direction or are completely insignificant. For example, EXTDAT, the ability to link a spreadsheet to an external database, has a large, positive coefficient in the Gandal regression. In our regression, we estimate a large, negative coefficient. The coefficient on LOCOMP, the ability to read and write Lotus 1-2-3 files, is slightly negative and insignificant in our regression as compared to the large premium estimated by Gandal. Note that in our model, we did not use ability to read and write Lotus 1-2-3

files as a measure of Lotus compatibility, but rather we estimated the value of offering a Lotus compatible menu-tree (LOTMENU). Using LOTMENU, we also find a significant value for Lotus 1-2-3 compatibility.

Also, the coefficients on the time dummy variables, while declining over time, are not significant in our regression. The time variable coefficients are very negative and significant in Gandal's regression.

We also applied Gandal's model all 125 of our product observations. We have added two additional time dummy variables to control for price differences in 1986 and 1992 as well as a variable called OSMAC to control for the presence of Macintosh products in the sample. The results of this are shown below in Table 45:

Table 45: Result's of Gandal's Preferred Model Applied to All Thesis Data

	Gandal Sample		Thesis Total Sample	
VARIABLE	**Coefficient**	**T-Stat**	**Coefficient**	**T-Stat**
CONSTANT	3.76	12.31	5.055	22.461
TIME86	--	--	-0.134	-0.566
TIME87	-0.06	-0.38	-0.269	-1.179
TIME88	-0.44	-2.67	-0.273	-1.128
TIME89	-0.70	-4.20	-0.425	-1.688
TIME90	-0.79	-4.90	-0.489	-1.945
TIME91	-0.85	-5.30	-0.681	-2.689
TIME92	--	--	-0.591	-2.095
EXTDAT	0.55	4.05	-0.102	-0.851
GRAPHS	0.46	3.51	0.453	2.349
LANCOM	0.21	1.65	0.348	2.545
LINKING	0.21	1.91	0.135	0.880
LMINRC	0.11	1.59	-0.019	-0.606
LOCOMP	0.72	5.28	0.126	0.546
LOTUS	0.56	4.36	0.681	5.623
OSMAC	--	--	0.253	1.785
WINDOW	0.17	2.14	0.212	2.369
N	91		125	
S.E. of Regression	0.385		0.480	
R-Squared	0.857		0.496	
Adjusted R-Squared	0.833		0.421	

This regression is largely the same as that applied to the thesis sub-sample presented above. The major difference is that the EXTDAT coefficient is negative and insignificant here while it was both negative and significant in the earlier regression.

We were obviously surprised by the differences we found in applying Gandal's model to our data set. However, we attribute these results to the differences in the underlying samples. It is possible that the variables used in Gandal's model are perhaps too basic to describe and differentiate our product sample adequately. Also, as we described in Section II above, our data set includes concurrent versions of products since we used units sold data to determine which products were actually sold in the market during a given year. It is plausible that Gandal's data set did not account for the possibility of product repetition and that this could exert significant influence on the results.

APPENDIX C: RESULTS OF BASIC HEDONIC MODEL IN NATURAL LOG FORM

Table 46: Basic Model Results in Natural Log Form

BASE CASE HEDONIC MODEL
(Natural Log of Real List Price is Dependent Variable)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
C	4.928	34.754	0.000
T86	-0.036	-0.154	0.878
T87	-0.223	-0.902	0.369
T88	-0.232	-0.902	0.369
T89	-0.456	-1.782	0.077
T90	-0.522	-2.051	0.043
T91	-0.792	-3.055	0.003
T92	-0.774	-2.723	0.008
CELLINKF	0.254	1.948	0.054
EMBEDCHT	0.438	2.572	0.011
LOTMENU	0.281	2.480	0.015
MFR_LOT	0.561	4.097	0.000
PROGRAM	0.345	1.566	0.120
SORTCOL	0.486	4.496	0.000
WYSIWYG	0.389	2.726	0.007
N	125		
S.E. of Regression	0.447		
R-Squared	0.555		
Adjusted R-Squared	0.498		

In this regression, PROGRAM is not significant and the significance of CELLINKF is very close to the 5% level. All other results are materially similar to the linear form results presented earlier in Section IV.

APPENDIX D: RESULTS OF BASIC HEDONIC MODEL WITH DEPENDENT VARIABLE REAL FACTORY PRICE

Table 47: Basic Model Results on Dependent Variable Real Factory Price

BASE CASE HEDONIC MODEL
(Real Factory Price is Dependent Variable)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
C	184.409	4.723	0.000
T88	-14.567	-0.370	0.713
T89	9.238	0.217	0.829
T90	-7.435	-0.171	0.865
T91	-91.505	-2.101	0.040
CELLINKF	16.264	0.492	0.624
EMBEDCHT	80.771	1.832	0.072
LOTMENU	79.714	2.585	0.012
MFR_LOT	118.636	3.329	0.001
SORTCOL	97.186	3.023	0.004
WYSIWYG	66.633	1.950	0.056
N	72		
S.E. of Regression	93.332		
R-Squared	0.540		
Adjusted R-Squared	0.464		

The basic hedonic model is applied here to the 72 products for which we had factory price information. Of these, 54 of the factory prices were supplied by DataQuest and 18 were estimated from information on revenues and units sold from IDC. The years covered by this sample run from 1987 to 1991. While we would have preferred to have used real factory price as the dependent variable in estimating our hedonic price equation, data could not be obtained for all products available in the spreadsheet market in any year. Thus, we opted to fit our model to real list price, which permitted us to include the largest number of products in the sample. As these results make clear, the choice of model is sensitive to the level of price used. For the 72 products considered here, the average factory price discount relative to product list price is 58%.

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