"PROFITABILITY UNDER AN OPEN VERSUS CLOSED SYSTEM"

by

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Abstract

This paper explores the conditions under which the profits of a system developer are greater or less under a closed system versus an open system. In this context a closed system is defined to be one in which a system manufacturer produces and sells both the main component and peripherals, and an open system is one in which the system manufacturer sells only the main component and allows free competition in the production of peripherals. A closed system allows the producer to price discriminate by using the peripherals as a tied good. A manufacturer who opens its system loses profits on the peripherals, but is compensated by increased profits on sales of the main component due to the greater competition in peripherals. The results show that an open system is likely to be more profitable: the more elastic demand is for the system; the more differentiated are the peripherals; and the greater is the share of the main component in the total system budget of the consumer. The results are illustrated using examples of different IBM computer systems.

1 Introduction

Many new high-technology products are actually systems consisting of two parts, a main component and peripherals. A leading example, which motivates this paper, is a computer system. The main component in this case is the CPU, and the peripherals include software, printers, and modems.[1] Peripherals can be produced by the system manufacturer or by third-party manufacturers who make their peripherals compatible with the system.[2] This division of a system leads to interesting problems for both producer and consumer. The producer of the system may be able to control whether or not it is possible to produce compatible third-party peripherals. Upon buying the main component, the consumer may decide to delay some or most purchases of peripherals into the future. The decision that the system manufacturer makes regarding the state of competition in peripheral production has an effect on the consumer's current and future purchases. This paper studies the effects of the system manufacturer's decision on profits and consumer surplus.

A system is considered to be closed if the system manufacturer controls the production of compatible peripherals. This control can arise either from property rights or design. One way to keep the system closed is to retain rights over the interface between the main component and peripherals. If the interface can not be legally protected, the producer could design an interface between the main component and peripherals that potential peripheral producers could not reverse engineer. The system is considered to be open if there is free competition in the production of

[1]Software beside the operating system of the computer, while technically not peripherals, can be included with the hardware peripherals in the analysis of this paper.

[2]For the purpose of this paper, the firm who created the original system, consisting in the computer example of, in part, the processor, operating system, and interface to the peripherals, is called the system manufacturer, even if the firm only produces CPUs and no peripherals.

peripherals. The system can be open either because the manufacturer chooses for it to be open or would like it to be closed but is unable to maintain a proprietary interface.

The system manufacturer faces a tradeoff between an open and a closed system. If the system is closed then the manufacturer earns profit on both the main component and sales of peripherals. If the system is open then competition takes place in both the price and variety of peripherals. The lower price and/or greater variety of peripherals in an open system make the system more attractive to consumers. This increases profits from the main component in an open system compared to a closed system. The cost to the system manufacturer of an open system is foregone monopoly profits on the sales of peripherals. This paper examines the conditions under which the increased profits on sales of the main component in an open system outweigh the lost profits on sales of the peripherals.

The history of the computer industry offers the example of a system manufacturer who at different times produced both an open and a closed system depending on the type of computer. The early mainframe computers of IBM in the 1950s and 1960s were what would be considered a closed system. While compatible peripherals and even CPUs were eventually produced by what came to be known as plug-compatible manufacturers (PCMs), IBM kept as much technical information as possible to themselves, which led to a lag between system introduction and PCM competition.[3] PCMs began producing peripherals for the IBM System/360 in the late 1960s

[3]In 1956, IBM signed a consent decree in order to settle an antitrust proceeding initiated by the Department of Justice. This consent decree required them to furnish upon request to any IBM owner all technical information that it provided to its own repair and maintenance people. In addition, IBM was required to grant unrestricted use of IBM patents to any IBM owner for a reasonable fee. This limited the ability of IBM to control the supply of plug-compatible hardware through either a proprietary interface or by design.

beginning with tape drives. Soon after the PCMs began selling compatible peripherals, IBM took two actions which are relevant to this model. First of all, IBM changed the interface between the mainframe and peripherals for new models. This had the effect of closing the system by discouraging the PCMs. In addition, IBM changed pricing strategy. During the period before plug-compatible peripherals were offered, IBM was able to earn high profits on peripherals. The high prices which IBM charged in fact induced the entry of the plug-compatible manufacturers, which forced IBM to change its pricing strategy by lowering the price of peripherals relative to the price of CPUs.

During the course of both the Department of Justice's antitrust case against IBM as well as PCMs' civil cases against IBM, there was much dissent over the causes and effects of IBM's actions. Depending on the viewpoint, the interface change was either in order to discourage PCMs or the change was simply due to a technological improvement. The price decrease on peripherals is viewed either as a vehicle to price out plug-compatible PCMs or as a natural response to increased competition. In this vein, the relative price increase on the CPU is viewed either as a means of recouping losses on peripherals, or simply as a (incomplete) response to inflation. What is important from the point of view of this paper is simply that after changing the interface IBM did not disseminate the new specifications as they would have with an open system, and the price changes resulted in a relatively higher price for the CPU with respect to the peripherals.[4]

In entering the personal computer market IBM chose exactly the opposite strategy. The first

[4] For a summary of the different viewpoints see both Gerald W. Brock, *The U.S. Computer Industry* (Cambridge, MA: Ballinger Publishing Company, 1975), Chapter 8, and Franklin M. Fisher, John J. McGowan, and Joen E. Greenwood, *Folded, Spindled, and Mutilated: Economic Analysis and U.S. v. IBM.* (Cambridge, MA: MIT Press, 1983), pp. 328-332.

successful personal computer was the Apple II, introduced in 1977. Apple chose to use proprietary systems for the Apple II as well as later models, with control over the operating system, the read-only memory (ROM), and eventually even the graphical user interface (the menus, icons, and windows which users manipulate to run the machine). All peripheral hardware and software produced by third parties were licensed, and in many cases sold under the Apple name. When IBM entered the market in 1981 with the IBM PC, it chose to use an open system. The operating system (DOS) was written by Microsoft, and the processor was made by Intel. In addition, all of the technical specifications were published in order to facilitate third-party development of software and hardware. The IBM PC architecture soon overtook Apple to become the industry standard.[5]

Strategic decisions concerning an open versus a closed system arise in other industries besides computers. Until challenged by the courts in the late1960s, AT&T required all consumers to buy phone equipment through their subsidiary, Western Electric. Although the decision to open the system caused AT&T to lose profits on the sales of peripherals, it is possible that the resulting access to more inexpensive peripherals, especially those which enable new forms of communication, such as faxes and modems, has increased profits on AT&T's long distance business. In Western Europe, where peripheral sales are still regulated, the governments face the choice of allowing their systems to be more open. Another example where a decision on the type of system must

[5]However, IBM soon lost CPU sales to compatible clones, beginning with the Compaq Portable in 1982. While IBM encouraged the production of third-party peripherals, they did not foresee the advent of low-cost clones. IBM has unsuccessfully taken various steps to regain control of the PC standard, including introduction of the proprietary Micro-Channel Architecture in the PS/2 series of personal computers and attempts to dislodge DOS and Windows with its proprietary OS/2 operating system. An interesting history of the IBM PC is contained in James Chposky and Ted Leonsis, *Blue Magic: The People, Power, and Politics behind the IBM Personal Computer* (New York: Facts on File Publications, 1988).

be made is local area networks (LANs), where the main component is the operating system and transmission method (eg. Token-Ring) and the peripherals are the network cards and gateways used to gain access to the LAN and networks outside the LAN.

This paper shows the conditions under which each type of system is more profitable. From the computer examples given above, a closed system seems to have been more viable in the mainframe world than in the personal computer world. In this model there are three factors affecting the relative profitability of an open versus a closed system. The first is the degree of differentiation between the available peripherals. The second is the elasticity of demand for the system as a whole. The final factor is the share of the total computer budget which is spent on peripherals. For the early mainframe computers there were few types of peripherals, which were mainly used for data storage. These peripherals were more substitutable for one another than are the various peripherals available today for personal computers. In addition, I argue that the demand for early computer systems was more inelastic than it is for personal computers, for which many more substitutes exist. Finally, unfortunately it is difficult to say at first glance whether the budget share spent on peripherals is greater or less with a personal computer or a mainframe. These observable differences between early mainframes and personal computers are used to explain why an open or closed system may have been more profitable, within the framework of this paper.

The model below has two stages. In the first stage, the system manufacturer announces whether the new system is open or closed and then sells the main component of the system. Consumers decide how much to spend on the main component based on the price of the main component and the resulting second-stage price and variety of peripherals. In the second stage there are sales of peripherals, which depend on the amount of the main component bought in the first period and the actual price and variety of peripherals. If the system is open there is monopolistic competition in peripherals. In this case, the monopolist can charge a relatively high price for the main component in order to appropriate the benefits that consumers derive from free competition in peripherals in the second stage. If the system is closed the monopolist produces peripherals. In this case the peripherals are a tied good where a relatively low price is charged for the main component in order to increase profits on sales of peripherals.

There has been relatively little work done in this area. A paper by Greenstein (1990) explores the design decision of a system producer facing perfect cloning of a single peripheral. The model shows the conditions under which the monopolist should manipulate the interface in order to delay entry of a third-party peripheral producer. If there is entry, the only benefit to consumers is a lower price for the peripherals. In this paper, I assume that consumers derive demand for peripherals from a Dixit-Stiglitz utility function. In this case openness not only leads to lower prices, but also a greater variety of peripherals. The increased variety leads the main component manufacturer to be further compensated for opening the system with even greater profits for the main component.

This work is related to two other lines of research. The first related area is that of market foreclosure through vertical integration (see, for example, Hart and Tirole, 1990). In this literature, full foreclosure of the downstream (peripheral) market, which we would call a closed system, is one of the possible outcomes of vertical integration between the main component manufacturer and a company manufacturing peripherals. In this paper for a closed system we simply assume that the downstream market is monopolized through property rights and then we study the effects on profits. There is no possibility of partial foreclosure of the downstream market. The second related area is the second-sourcing literature (see Farrell and Gallini, 1988, and Shepard, 1987). In the context of this literature, an open system could be viewed as an ex ante commitment to lower future prices for peripherals in order to convince people to purchase the main component. Whereas in the second-sourcing literature licensing leads to limited competition in an identical good, in this paper the commitment to an open system, leading to monopolistic competition in peripherals, provides a greater variety to consumers while depriving the system manufacturer of any future profits to be made on peripherals.

The model is presented in Section 2. The demand for both the main component and peripherals is derived and profit-maximization for both stages is shown with both an open and a closed system. In addition, a measure of consumer surplus and welfare is presented. Section 3 shows the conditions under which a system should be open or closed. The mainframe and personal computer examples given above are examined in the context of the results presented in Section 3. Finally, Section 4 contains the conclusion.

2 Model

This section contains a model used to explore the conditions under which a monopoly producer of a system would want to keep the system closed or allow it to be open. In the first part of this section the demand functions for the main component and the peripherals are derived from a standard utility function. In the next part of this section the two-stage profit maximization for the system components is shown. In the first stage of the model the system manufacturer sells main components. In the second stage peripherals are sold. If the system is closed the system manufacturer also sells peripherals. If the system is open then third-party companies sell compatible peripherals.

2.1 Consumers

All consumers are assumed to have identical preferences. Without a loss of generality the following analysis can be done for a representative consumer.

2.1.1 Utility

The representative consumer is assumed to have a utility function similar to that found in Krishna et al.(1989);

$$U(y, X) = y + U(X) \tag{1}$$

where y is a competitively supplied numeraire good and $U(X)$ is a subutility function of the form;

$$U(X) = \beta X^{\alpha} \tag{2}$$

where X is a composite index of the system which is consumed. It is assumed that $0 < \alpha < 1$ for concavity, and that $\beta > 0$. The presence of the numeraire good in the utility function implies that the total amount of money that the consumer budgets for buying a computer system is variable.

The system X is a Cobb-Douglas function of the main component, x_0, and a composite index of the peripherals, x_p,

$$X = x_p^{\mu} x_0^{1-\mu} \tag{3}$$

where $0 < \mu < 1$ for concavity.[6] The Cobb-Douglas subutility function implies that the consumer spends a fixed proportion of the amount budgeted for a system on the two parts according to the magnitude of μ. . The composite price of the computer system is:

$$P = K p_p^{\mu} p_0^{1-\mu} \tag{4}$$

where p_0 is the price of the main component and p_p is the composite price of the peripherals, and $K = \mu^{-\mu}(1-\mu)^{\mu-1}$.[7]

There are assumed to be n peripherals. The composite index of peripheral consumption, x_p, is simply a Dixit-Stiglitz function of the individual peripherals:

$$x_p = \left[\sum_{i=1}^{n} x_i^{\rho}\right]^{\frac{1}{\rho}} \tag{6}$$

where $0 < \rho < 1$ so that the peripheral index is concave and the peripherals are imperfect

[6] For a representative consumer x_0 can be thought of as a hedonic index of some important feature of the main component. In the computer analogy it can index certain attributes of the CPU such as the speed of the processor or the amount of random-access memory (RAM).

[7] The price index is derived from the Cobb-Douglas expenditure function:

$$e(p_0, p_p, X) = K p_p^{\mu} p_0^{1-\mu} X. \tag{5}$$

substitutes for one another. The elasticity of substitution between peripherals is $\sigma = -\frac{1}{1-\rho}$. The composite price of peripherals equals:

$$p_p = \left[\sum_{i=1}^{n} p_i^r\right]^{\frac{1}{r}}. \tag{7}$$

where $r = \frac{\rho}{\rho-1}$.[8]

2.1.2 Demand

The consumer's demand for system services is derived as in Krishna et al. (1989) by setting the marginal utility of the system equal to the marginal cost. From the utility function (1) the marginal utility equals $\alpha\beta X^{\alpha-1}$. The marginal cost to the consumer of system services equals the price. Therefore,

$$X(P) = \left(\frac{P}{\alpha\beta}\right)^{\frac{1}{\alpha-1}}. \tag{9}$$

The elasticity of demand for the system is defined to be:

$$\epsilon_X = \frac{\partial X}{\partial P}\frac{P}{X} = -\frac{1}{1-\alpha}. \tag{10}$$

In the second period the consumer purchases peripherals, based on the existing stock of the

[8]The price index is derived from the peripherals expenditure function:

$$e(p_1, ..., p_n, x_p) = \left[\sum_{i=1}^{n} p_i^r\right]^{\frac{1}{r}} x_p. \tag{8}$$

main component and the actual price of peripherals. The utility-maximizing level of each peripheral is simply where its marginal utility equals its price. This is solved given the quantity of the main component, x_0, purchased in the first period. The demand for any peripheral becomes:

$$x_i(p_i, p_p, x_0) = p_i^{\frac{1}{\rho-1}} p_p^{\frac{\rho-\mu\alpha}{(\rho-1)(\mu\alpha-1)}} x_0^{\frac{\alpha(1-\mu)}{1-\mu\alpha}} [\alpha\mu\beta]^{\frac{1}{1-\mu\alpha}}. \tag{11}$$

As in Dixit, Stiglitz (1977), n is assumed to be large enough so that the effect of each price change on the peripheral price index, p_p, is negligible, i.e. $\frac{\partial p_p}{\partial p_i} = 0$. In this case the elasticity of demand for an individual peripheral with respect to its own price, holding all other prices constant, is:

$$\epsilon_{ii} = \frac{\partial x_i}{\partial p_i}\frac{p_i}{x_i} = -\frac{1}{1-\rho}. \tag{12}$$

This is the elasticity of the Chamberlinian *dd* curve.

If all peripherals are assumed to be symmetrical, then $p_p = pn^{\frac{1}{\rho}}$, and demand for any peripheral x is:

$$x(p, n, x_0) = p^{\frac{1}{\mu\alpha-1}} n^{\frac{\rho-\mu\alpha}{\rho(\mu\alpha-1)}} x_0^{\frac{\alpha(1-\mu)}{1-\mu\alpha}} [\alpha\mu\beta]^{\frac{1}{1-\mu\alpha}}. \tag{13}$$

If the price level, p, of all of the peripherals were to rise, the elasticity of demand for an individual peripheral is:

$$\epsilon = \frac{\partial x}{\partial p}\frac{p}{x} = -\frac{1}{1-\mu\alpha}. \tag{14}$$

This is the elasticity of the *DD* curve.

The dd curve is more elastic than the DD curve when

$$\rho > \mu\alpha. \tag{15}$$

When this condition holds, the peripherals must be substitutes for one another because the optimal coordinated policy is to raise all prices simultaneously to face the more inelastic DD curve and increase the markup per peripheral. Examining the cross-price elasticity:

$$\epsilon_{ij} = \frac{\partial x_i}{\partial p_j}\frac{p_j}{x_i} = \frac{\rho - \mu\alpha}{n(\rho - 1)(\mu\alpha - 1)} \tag{16}$$

one sees that if and only if condition (15) holds, the elasticity is positive so that the peripherals are substitutes, although for large n the magnitude of the elasticity is negligible.

In the first period the consumer buys the main component based on the expected price and variety of peripherals, which in turn is a function of the price of the main component. The utility-maximizing demand for the main component, x_0, is simply derived from the expenditure function for the system using Shepard's lemma:

$$x_0(p_0, p_p^e) = \frac{\partial e(p_0, p_p, X)}{\partial p_0} = (1-\mu)K p_p^{e^{\mu}} p_0^{-\mu} X(P), \tag{17}$$

where demand is a function of the given price of the main component and the expected price of peripherals.

If the peripherals are symmetric then using (9) and (17) demand for the main component is:

$$x_0(p_0, p^e, n^e(p_0)) = \frac{(1-\mu)K^{\frac{\alpha}{\alpha-1}}}{(\alpha\beta)^{\frac{1}{\alpha-1}}} n^e(p_0)^{\frac{\mu\alpha}{\rho(\alpha-1)}} p^{e^{\frac{\mu\alpha}{\alpha-1}}} p_0^{\frac{1-\mu\alpha}{\alpha-1}}, \tag{18}$$

where $n^e(p_0)$ and p^e are derived as in Section 2.2.2 depending on whether the system is open or closed. The elasticity of demand for the main component equals

$$\epsilon_0 = \frac{\partial x_0}{\partial p_0}\frac{p_0}{x_0} = -\frac{(\rho-\mu\alpha)(1-\mu\alpha)}{\rho\alpha-\rho+\mu\alpha-\rho\mu\alpha^2+\mu^2\alpha^2\rho-\mu^2\alpha^2}. \tag{19}$$

This elasticity is negative under the condition that

$$\rho > \frac{\mu\alpha}{1-\alpha+\mu\alpha}. \tag{20}$$

The analysis of this model is restricted to this range.

The cross-price elasticity of aggregate peripherals with respect to the price of the main component is:

$$\epsilon_{p0} = \frac{\partial x_p}{\partial p_0}\frac{p_0}{x_p} = \frac{\alpha(1-\mu)(1-\mu\alpha)}{\rho\alpha-\rho+\mu\alpha-\rho\mu\alpha^2+\mu^2\alpha^2\rho-\mu^2\alpha^2}. \tag{21}$$

Under condition (20), $\epsilon_{p0} < 0$ and hence the main components and peripherals are complements.

2.2 Firms

I assume that the system does not face any competition. Competition could potentially take two forms. The first is direct competition from compatible CPUs, or cloning, which the system manufacturer is assumed to be able to prevent. The second type is competition from close substitutes to the system, which is assumed to be nonexistent in this model. Another assumption is that the system producer can keep the system closed if desired by controlling the property rights over the interface rather than by designing the interface in such a way that it is difficult to reverse engineer. This implies that the system costs the same to design and produce whether it is open or closed.

In the first stage of competition the system manufacturer sells the main component. In the second stage, if the system is open there is monopolistic competition in peripherals. If the system is closed the system manufacturer sells the peripherals in the second stage. The system manufacturer makes a credible announcement as to whether the system is open or closed before consumers purchase the main component. The system is solved backwards in order to determine the effect of first-stage main component sales on the price and variety of peripherals. In the second stage, the price and variety are solved for as a function of the stock of main components sold in the first period. In the first period, the profit-maximizing price of main components is determined based on how this will affect the second-stage variables.

2.2.1 Profits

The cost of producing the main component is c_0. There are assumed to be n types of peripherals, which are assumed to be symmetrical. The peripherals are produced at marginal cost c, and each variety of peripheral has a fixed cost F. All costs are the same whether the system is open or closed, implying that making a system closed does not require design changes which increase costs.

If the system is closed, the system manufacturer earns profits from sales of both the main component and peripherals:

$$\pi^c = x_0^c(p_0^c;\cdot)(p_0^c - c_0) + n^c\pi_i^c \tag{22}$$

where the profit earned on each peripheral is:

$$\pi_i^c = x^c(p^c;\cdot)(p^c - c) - F. \tag{23}$$

If the system is open the system manufacturer only earns profits on the main component:

$$\pi^o = x_0^o(p_0^o;\cdot)(p_0^o - c_0). \tag{24}$$

Each individual peripheral producer earns profits:

$$\pi_i^o = x^o(p^o;\cdot)(p^o - c) - F. \tag{25}$$

2.2.2 Stage 2

In this stage the price and variety of peripherals are determined. The peripheral producer in either type of system simply sets the profit-maximizing price for the peripheral. The demand curve that the peripheral producer perceives to face is different depending on whether the system is open or closed. The peripherals are assumed to be differentiated from one another. The number of types of peripherals produced is determined by the system manufacturer if the system is closed. If the system is open there is monopolistic competition in the production of peripherals. Each peripheral is assumed to be produced by a separate firm. Thus, the variety of peripherals is determined by the free entry of peripheral producers until profits equal zero.

The system manufacturer retains two advantages by keeping the system closed. The first advantage is that the firm can raise or lower the price level for all peripherals simultaneously. When the peripherals are substitutes for one another the system manufacturer faces the more inelastic demand curve DD and can therefore profitably set a price above that which individual peripheral producers would charge. The second advantage is that the closed-system manufacturer controls the number of peripherals. By preventing entry of peripheral producers, the monopolist can avoid the monopolistic competition outcome of zero profits on peripherals.

In an open system, each peripheral producer i must take all other prices as given and thus faces the dd curve. The number of peripherals, n, is assumed to be large as in Dixit, Stiglitz (1977), and therefore $\epsilon_{ii} = -\frac{1}{1-\rho}$. Given this elasticity and the first-order condition for profit-maximization of π_i^o the price is:

$$p_i^o = \frac{c}{\rho}. \tag{26}$$

If the system is closed, the monopolist, who can set the price for every peripheral, faces the DD demand curve with elasticity $\epsilon = -\frac{1}{1-\mu\alpha}$. Maximizing profit π_i^c results in the price:

$$p^c = \frac{c}{\mu\alpha}. \tag{27}$$

Under condition (15) that the peripherals are substitutes, it is easy to see that $p^c > p_i^o$. The price under a closed system is higher because the monopolist faces the more inelastic demand curve DD, and can therefore charge a higher markup.

Free entry of peripheral producers takes place if the system is open. Assuming that all peripherals are symmetric leads to the zero-profit condition

$$x(p^o;\cdot)(p^o - c) - F = 0 \tag{28}$$

or

$$\pi_i^o = 0 \tag{29}$$

for every peripheral produced.

The zero-profit condition is solved for n^o given the constant price of peripherals, p^o, and the amount of main component bought, x_0^o:

$$n^o = \left[\frac{(p^o - c){p^o}^{\frac{1}{\mu\alpha - 1}} {x_0^o}^{\frac{\alpha(1-\mu)}{1-\mu\alpha}} [\alpha\mu\beta]^{\frac{1}{1-\mu\alpha}}}{F} \right]^{\frac{\rho(1-\mu\alpha)}{\rho-\mu\alpha}} . \tag{30}$$

If the system is closed, the monopolist determines the profit-maximizing number of peripherals by maximizing total peripheral profits $n\pi_i^c$ in n:

$$\mathrm{Max}_n \; n\pi_i^c = n[x(n;\cdot)(p^c - c) - F]$$

$$FOC : \pi_i^c + nx'(\cdot)(p^c - c) = 0. \tag{31}$$

Given the price of peripherals, the monopolist solves the first-order condition for:

$$n^c = \left[\frac{(p^c - c) p^{c^{\frac{1}{\mu\alpha - 1}}} x_0^{c^{\frac{\alpha(1-\mu)}{1-\mu\alpha}}} [\alpha\mu\beta]^{\frac{1}{1-\mu\alpha}} \frac{\mu\alpha(\rho-1)}{\rho(\mu\alpha-1)}}{F} \right]^{\frac{\rho(1-\mu\alpha)}{\rho-\mu\alpha}} . \tag{32}$$

From demand curve (13) it is easy to show that $x'(n^c; \cdot) < 0$ under condition (15) that the peripherals are substitutes, implying that the DD curve shifts left as the number of peripherals increases. Given that $x'(n^c; \cdot) < 0$ one can compare Equations (31) with (29) to see that $\pi_i^c > \pi_i^o$. By controlling the price and number of peripherals in a closed system, the system manufacturer makes positive profits on the sales of each peripheral. The profits represent the opportunity cost to the system manufacturer of an open system.

2.2.3 Stage 1

In the first stage the system manufacturer sells main components. Consumers purchase main components based on the price of the main component and the resulting price and variety of peripherals. By substituting $x_0(p_0, p^e, n^e)$ into $n(x_0)$ from above, one can solve for $n^e(p_0)$ and determine the effect of the price of the main component on the resulting variety of peripherals.

If the system is open the system manufacturer simply sets the profit-maximizing price for main components. If the system is closed, the system manufacturer sets a price for main components which maximizes profits for the whole system. This takes into account the effect of the price of the main component on profits from peripherals in the second period. As long as the main component and peripherals are complements, the monopolist treats peripherals as a tied good and lowers the relative price of the main component.

If the system is open the main component manufacturer maximizes profits π_0^o in price. Given the elasticity ϵ_0 in Equation (19), the price can be solved from the first-order condition:

$$p_0^o = \frac{c_0(\rho - \mu\alpha)}{\rho\alpha(1-\mu)}. \tag{33}$$

If the system is closed the monopolist sets a price for the main component which maximizes total system profits π^c. The first-order condition can be solved for the price:

$$p_0^c = \frac{c_0(\rho - \mu\alpha)}{\alpha(\rho - \mu^2\alpha)}. \tag{34}$$

Under condition 20 that the elasticity of demand for the main component is negative it can easily be shown that $p_0^c < p_0^o$, implying that the closed-system monopolist treats the peripherals as a tied good and sets the main component price lower with a closed system in order to increase demand for peripherals.

2.3 Welfare

Consumer surplus is defined to be total utility minus expenditures:

$$\begin{aligned} CS(X) &= \beta X^\alpha - PX \\ &= \beta \left[n^{\frac{\mu}{\rho}} x^\mu x_0^{1-\mu} \right]^\alpha - nxp - x_0 p_0 \end{aligned} \tag{35}$$

where all n peripherals are symmetrical. Welfare is defined to be consumer surplus plus profits.

3 Results

This section contains results showing the conditions under which open-system profits for the system manufacturer would be greater or less than closed-system profits. There are three parameters of interest in this model: μ, the allocation of the system budget between the main component and peripherals; α, the parameter characterizing the elasticity of demand for the system ($\epsilon = -\frac{1}{1-\alpha}$); and ρ, the parameter characterizing the elasticity of substitution between peripherals ($\sigma = -\frac{1}{1-\rho}$). Each of these parameters is bounded between zero and one. The profitability of an open versus a closed system is examined only when the parameters meet conditions (15) and (20). These conditions must hold for the main component and aggregate peripherals to be complements, and for the individual peripherals to be substitutes for one another.

Of the three parameters, α, ρ, and μ, perhaps μ is the easiest to observe. Anyone with a personal computer could easily determine *ex post* the share of their computer budget spent on each part of their system. More importantly, *ex ante* it may be simple for a system producer to approximate what μ would be given the nature of the system. For instance, it is likely that the percentage of the budget to be spent on peripherals is much higher for a PC than for a supercomputer. The analysis here assumes that the peripheral share is exogenous, as this model, and not a function of the pricing, which in turn would be affected by the decision to keep the system open or closed. The results below are given for three broad types of systems, one with a high peripheral share ($\mu = .75$), a medium peripheral share ($\mu = .5$), and a low peripheral share ($\mu = .25$).

Due to the complexity of the system it is not feasible to present an analytical solution. However, given the fact that there are only three parameters of interest, each of which is bounded between zero and one, a graphical solution can be presented which is highly instructive. The following three figures show the conditions under which profits are greater when the system is open or closed for the groups of systems defined above. The lowest line in each of the three figures is the border where profits under an open system just equal those of a closed system. Values of α and ρ which are below and to the right of the line correspond to greater profits for a closed system, and above and to the left of the line profitability is greater with an open system. Given the value of μ, the relationship between α and ρ when $\pi^o = \pi^c$, as represented by the lowest line in the figures, is linear:

$$\alpha = k\rho \tag{36}$$

where k is defined implicitly as a function of μ by the following equation:

$$(k\mu)^{-k\mu} = \left(\frac{1 - k\mu^2}{1 - \mu}\right)^{1-k\mu}. \tag{37}$$

This relationship is derived in the Appendix.

The middle concave line of the figures represents the upper boundary of condition (20) that the peripherals and main component are complementary goods. The system is not considered for values of ρ and α up and to the left of this line.[9] Finally, the top dashed line represents the upper boundary for condition (15) that the peripherals are substitutes for one another. This boundary is dominated by condition (20), represented by the middle line, so it is never binding.

The greater the share μ that consumers spend on peripherals the more potential profits there are from sales of peripherals. Therefore, the system monopolist is more likely to keep the system closed and earn profits on sales of peripherals, the greater the share of the system budget to be spent on peripherals. Comparing the three figures we see that the area where a closed system is more profitable is larger, the greater is μ. The slope of line where $\pi^o = \pi^c$ increases in μ, in other words $k'(\mu) > 0$.

The parameter ρ is a measure of the differentiation between peripheral types. The greater is ρ, the greater is σ, the elasticity of substitution between peripherals, and the more substitutable one peripheral is for another. We have seen that keeping the system closed results in a higher price and, for all relevant parameter values explored here, a smaller variety of peripherals than in an open system. The more substitutable the peripherals are for one another, the less consumers are affected by the low variety resulting from a closed system. In addition, the cross-price effects on sales of raising the price level for all peripherals under a closed system are the largest when ρ is high. Therefore, all things equal, the greater is the degree of substitution between peripherals, the more likely the system is to be more profitable when closed.

The elasticity of demand for the system as a whole equals $-\frac{1}{1-\alpha}$. Therefore, the lower α, the more inelastic is demand. If demand for the system is relatively inelastic, it is more profitable

[9] When condition (20) is violated the model is unstable. This can be seen by substituting $x_0(n^e;\cdot)$ into $n(x_0)$ to get $n(n^e;\cdot)$. When the condition is violated $n'(n^e;\cdot) > 1$ and the model does not converge on a stable equilibrium.

to retain market power over the whole system. This is confirmed in the figures, where for low α profits are likely to be greater when the system is closed, given the values of μ and ρ.

As a rule then, systems for which demand is relatively inelastic, peripherals are easily substitutable, and peripherals make up a relatively large share of the total system budget are more profitable if kept closed. This combination characterizes the early mainframe computer systems of IBM. The System/360, which was introduced in 1964, had few different types of easily substitutable peripherals, mainly for data storage (tape and disk drives and punch-card equipment) and output (printers). Demand was fairly inelastic due to the few options available to users. Ratchford and Ford (1976, 1979) estimate the elasticity of demand for IBM computers in 1964 to be -1.85.[10] Finally, a commonly cited estimate of μ for these computer systems is 0.5. In Figure 2 for a high ρ corresponding to the low variety of peripherals, a closed system is profit-maximizing. IBM in fact chose a closed system, and then defended it against competition from plug-compatible peripherals.

The more elastic demand for the system, and the more differentiated the peripherals, the more likely an open system would lead to higher profits. Personal computers may be characterized in this fashion. A wider variety of peripherals is available (printers, disk drives, scanners, modems, etc.) than for early mainframes, and the different peripherals are less substitutable for one another as they perform more specialized functions. In addition, demand is probably more elastic than it was for early mainframes as users now have many options besides personal computers, including remaining with a mainframe. It is difficult to generalize what the share of peripherals in a computer

[10] This estimate overstates the elasticity of demand for systems as a whole because of the availability of substitutes for IBM systems. Therefore, these results are not totally applicable to IBM's decision, as I assume no system competition.

system is, however, it is probably no greater than the estimate for early mainframes cited above. This implies values of the parameters that are more likely to fall in the region of the figures where an open system would maximize profits, and indeed IBM chose an open architecture when they entered the personal computer market.

I was unable to compare analytically welfare or consumer surplus under an open versus a closed system due to the complexity of the variables. Numerically, both consumer surplus and welfare are greater under an open versus a closed system in all applicable regions of Figures 1-3. In terms of consumer surplus, this implies that the benefits of increased variety and lower prices for peripherals under an open system outweigh the effects of the corresponding increased price of the main component as compared to a closed system. In the area of the figure where closed-system profits outweigh open-system profits, the consumer surplus gain from an open system outweighs the profit shortfall to make welfare greater under an open system.

Figure 1: Profitability conditions for a high peripheral share ($\mu = .75$).

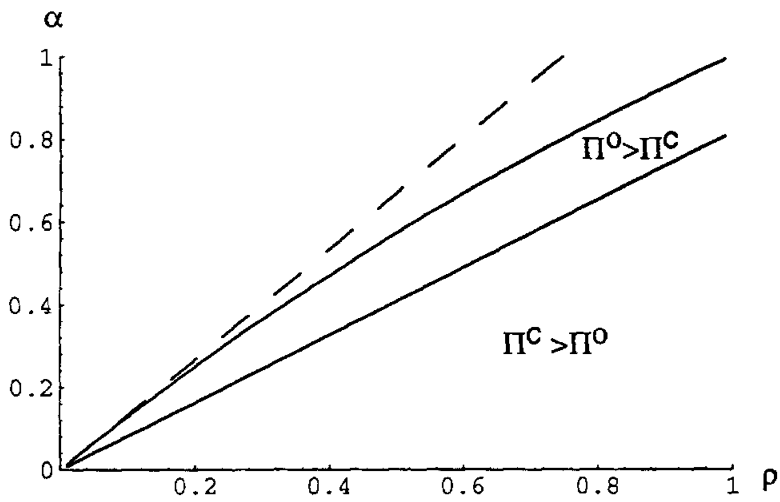


Figure 2: Profitability conditions for a medium peripheral share ($\mu = .5$).

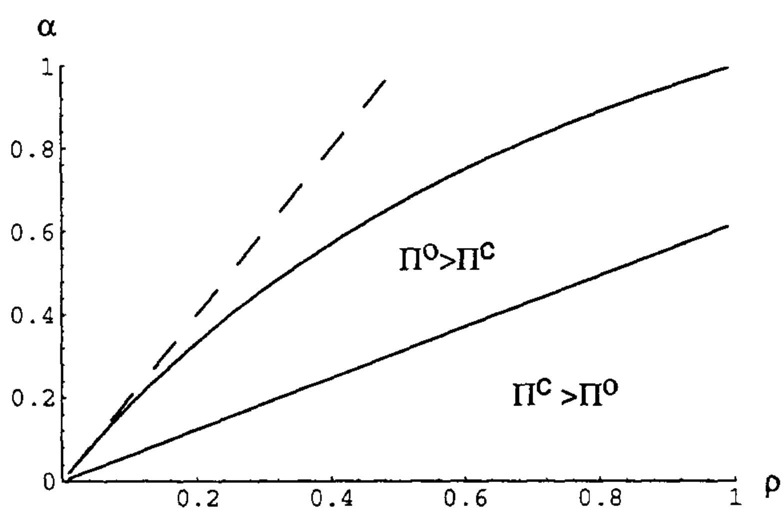
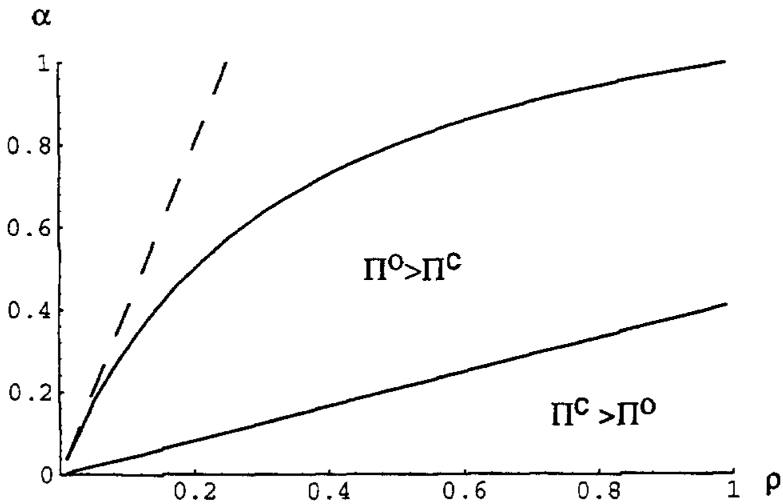


Figure 3: Profitability conditions for a low peripheral share ($\mu = .25$).



4 Conclusion

The results presented in this paper offer guidelines to system manufacturers contemplating the choice between an open or a closed system. The results show conditions under which a closed system is more or less profitable than an open system, based on the values of the main parameters of interest. The model illustrates the tradeoff between making profits on peripherals in a closed system and higher profits earned on the main component in an open system. If the system is kept closed then the system manufacturer sets a low price for the main component in order to boost later demand for peripherals. If the system is open then there are generally a greater variety of peripherals available at a lower price. This stimulates demand for the main component, which can be sold at a higher price then in the closed system.

IBM has used both closed and open systems at various times in its history. The fact that IBM effectively hindered plug-compatible peripherals by not disseminating information on the interface between its System/360 mainframe and peripherals suggests that IBM felt that a closed system was optimal. At a first glance available parameter estimates support IBM's choice using the results presented here. When plug-compatible manufacturers eventually opened up the System/360 in the late 1960s, IBM responded in part by lowering the relative price of peripherals with respect to the price of CPUs. This response is consistent with the predictions that this model makes about pricing under different system regimes. Estimating the direction of the changes in the relevant parameters for personal computer systems as opposed to mainframes shows that IBM's choice of an open system for the PC may also have been optimal.

The social optimum for any system, without side payments, is marginal cost pricing of the main component and the monopolistic competition result of average cost pricing of the peripherals. Short of achieving this outcome an open system maximizes welfare, because the benefits in terms of consumer surplus always outweigh any potential profit losses resulting from an open system. To the extent that the 1956 consent decree made IBM systems any more open then they would have been otherwise, welfare was increased, at the probable expense of IBM profits.

The next steps in this line of research are as follows. First of all, more data could be gathered about the relevant parameters for mainframe and PC systems in order to more concretely place each system in the figures presented here. Second of all, the assumption of no system competition could be relaxed in two ways. Along the lines of this paper the possibility of clones of the main component could be introduced to determine any conditions under which a system manufacturer would find it profit-maximizing to allow clones to be produced. Another type of system competition to introduce is that of close substitutes to the system. The introduction of close substitutes leads to a dynamic model where strategic moves are possible. For instance, a first-mover could preempt entry using an open system, or if the incumbent system is closed an entrant could gain a second-mover advantage by using an open system.

5 Appendix

This appendix shows how to derive the linear condition existing between α and ρ when open system profits equal closed system profits. Profits under a closed system equal:

$$\pi^c = x_0^c(p_0;\cdot)(p_0^c - c_0) + n^c(p_0;\cdot)[x^c(p_0;\cdot)(p^c - c) - F] \tag{38}$$

The first-order condition is:

$$x_0^{c'}(\cdot)(p_0^c - c_0) + x_0^c + n^c(\cdot)[x^c(\cdot)(p^c - c) - F] + n^c x^{c'}(\cdot)(p^c - c) = 0. \tag{39}$$

The first-order condition can be solved to be:

$$n^c(\cdot)[x^c(\cdot)(p^c - c) - F] = -x_0^c(\cdot)(p_0^c - c_0)\left[\frac{\rho - \mu\alpha}{\rho\alpha(1-\mu)}\right] - \delta x_0^c p_0^c \tag{40}$$

where $\delta = \frac{\rho\alpha - \rho + \mu\alpha - \rho\mu\alpha^2 + \mu^2\alpha^2\rho - \mu^2\alpha^2}{\rho\alpha(1-\mu)(1-\mu\alpha)}$. This can be substituted into π^c above.

The condition that open system profits equal closed system profits becomes:

$$x_0^o(p_0^o - c_0) = x_0^c(p_0^c - c_0)\left[\frac{\rho\alpha - \rho\alpha\mu - \rho + \mu\alpha}{\rho\alpha(1-\mu)}\right] - c x_0^c p_0^c. \tag{41}$$

Both p_0^o and p_0^c are functions of α, μ, ρ, and c_0. Substituting into the above equation one can solve that $\pi^c = \pi^o$ when $x_0^c = x_0^o$.

The condition that $x_0^c = x_0^o$ can be distilled to:

$$\frac{\rho^{\rho}}{(\alpha\mu)^{(\alpha\mu)}} = \left(\frac{\rho - \alpha\mu^2}{1-\mu}\right)^{\rho-\alpha\mu}. \tag{42}$$

Substituting $\alpha = k\rho$ into the above equation results in equation (37) that k is an implicit function of μ:

$$(k\mu)^{-k\mu} = \left(\frac{1 - k\mu^2}{1-\mu}\right)^{1-k\mu}. \tag{43}$$

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