E C O N O M I C S   B U L L E T I N

Indirect Network Effects and Trade Patterns

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Abstract

Indirect network effects exist when the utility of consumers is increasing in the variety of complementary products available for use with an electronic hardware device. In this note, we examine how indirect network effects work as a determinant of trade patterns. For these purposes we construct a simple two-country model of trade with incompatible country-specific hardware technologies. We show that trade patterns are determined by the interaction between hardware differentiation and indirect network effects due to software availability.

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1 Introduction

Indirect network effects exist when the utility of consumers is increasing in the variety of complementary software products available for an electronic hardware device. Examples of such devices include personal computers, video casette recorders, and consumer electronics products. Despite the fact that many industries characterized by indirect network effects are crucially related to growing world trade, the literature on indirect network effects is almost exclusively focused on closed economies.[1] Since the role of indirect network effects is amplified in the globalized world,[2] it seems important to explore the role of indirect network effects as a determinant of trade patterns.

As our primary contribution, we examine how trade patterns are determined in the presence of indirect network effects. For these purposes we construct a simple two-country model of trade with incompatible country-specific hardware technologies which is an extension of Church and Gandal's (1992) closed-economy model. Assuming that the distribution of the tastes of consumers are mirror images of each country's distribution, we show that trade patterns are determined by the interaction between hardware differentiation and indirect network effects due to software availability.

The rest of the paper is organized as follows. Section 2 describes the basic model. Section 3 describes the trading equilibrium. Section 4 contains concluding remarks.

2 The Model

Suppose that there are two countries in the world, Home and Foreign. In each country there are three types of goods: hardware, a large variety of software products, and the outside good. We assume that there are country-specific hardware technologies: *Home hardware* and *Foreign hardware*. We also assume that the hardware technologies are incompatible: software written for one country's hardware will not work with the other country's. The char-

[1] The seminal contributions on the role of a "hardware/software" system are Chou and Shy (1990) and Church and Gandal (1992). See Gandal (2002) for surveys.

[2] Gandal and Shy (2001, p. 364) notes that, in 1992, it was estimated that seventy-two percent of all personal computers throughout the world were IBM-compatibles. That is, they ran the MS-DOS operating system and were compatible with applications software written for the MS-DOS operating system. Accordingly, Gandal (2001) argues that it would be interesting to quantify trade flows in this industry over time.

acterization (i.e., location) of the two country-specific hardware technologies is exogenous: each is located at the end point of the unit line: let Home technology be at the left end point and Foreign technology at the right end point. We denote the marginal cost of hardware production in each country by c, which implies there are no sources for comparative advantage. We further assume that the hardware technologies are non-proprietary and that they will be offered at marginal cost. In this section, we consider the Home autarky situation where only Home hardware is available.

Consumer preferences over the combination of hardware and software are modelled as a CES utility function.[3] We assume that the distribution of the tastes of Home consumers is decreasing along a line of unit length $t \in [0, 1]$. We also assume that the density of type t consumers in Home is $1-t$: the total number of Home consumers is 1/2. Consumer densities are mirror images of each other: in Foreign, the density of type t consumers is t.

The preferences of a consumer of type t for a system are:

$$U(t) = [\sum_{i=1}^{n} (x_i)^{\theta}]^{(1/\theta)} + \phi - kt, \quad 1/2 < \theta < 1, \tag{1}$$

where n is the number of software products written for the Home hardware, x_i is the level of consumption of software product i, $\sigma \equiv 1/(1-\theta) > 2$ is the elasticity of substitution between every pair of software products, ϕ is the standalone benefit of the hardware, and we assume that $\phi > k$. k is the parameter which measures the degree of differentiation of two hardwares.

The representative consumer who purchases the hardware will maximize (1) subject to the following budget constraint: $\sum_i^n p_i x_i = e - c$, where p_i is the price of Home software variety i, e is the total expenditure allocated to hardware and software, and c is the price (i.e., cost) of a unit of Home hardware. The solution to this problem consists of the following demand functions:

$$x_i = (e - c)P^{\sigma-1}/p_i^{\sigma}, \tag{2}$$

where

$$P = [\sum_{j=1}^{n} (p_j)^{1-\sigma}]^{1/(1-\sigma)}. \tag{3}$$

The indirect utility of a type-t consumer who purchases a Home system is

$$V(t) = n^{1/(\sigma-1)}(e - c)/p + \phi - kt. \tag{4}$$

[3] See, Chou and Shy (1990) and Church and Gandal (1992).

The technology for the production of software is characterized by increasing returns to scale. We denote the constant marginal cost of software production for every product by b, and the software development cost by f. It is assumed that, if Home firms develop software products for Foreign hardware, there is an additional fixed cost g: it can be interpreted as a cost for collecting information about Foreign technology.[4] We also assume that software firms are monopolistic competitors, and thus, each product is priced at a markup over marginal cost b: $p = b\sigma/(\sigma - 1)$. Then the profit of a Home software firm is[5]

$$\pi = (p - b)(x/2) - f, \tag{5}$$

where $x = (e - c)/np$. In the autarky situation in which only Home hardware exists, all Home software firms choose to provide software that is compatible with Home hardware. The number of Home software firms is determined via free entry as follows: $n^A = (e - c)/2f\sigma$, where A refers to the autarky value.

3 Trading Equilibrium

The commencement of trade implies two basic changes in the market: (a) both Home and Foreign hardware devices are available to all consumers, and (b) the distribution of consumers' tastes is uniform along the line and the total number of consumers becomes 1.

The timing of the game is as follows:[6] In the first stage software firms enter the industry. There is free entry into the software industry and software firms have rational expectations. Although there may be more than one equilibrium software configuration, we show that the free-entry number of software firms, $N = n + n^*$, is unique, where n and n^* are the number of firms providing software for Home and Foreign hardware, respectively. In the second stage, software firms simultaneously choose which platform to provide software for. In the final stage, each consumer purchases either a Home or a Foreign hardware system and some of the compatible software. We solve this problem backward.

[4] This assumption implies that software products for one country's hardware are produced by firms located in that country.

[5] Note that the total size of the Home consumer is 1/2.

[6] This is taken from Church and Gandal's (1992) closed-economy model.

3.1 Final Stage

Since we assume the marginal costs (prices) of hardware and software are equal for both systems, consumers determine which hardware to purchase considering only their tastes and the amount of software available for each system. From (4), a consumer located at t purchases Home hardware if the following inequality holds:

$$n^{1/(\sigma-1)}(e-c)/p+\phi-kt > (N-n)^{1/(\sigma-1)}(e-c)/p+\phi-k(1-t), \quad (6)$$

where use has been made of the equation $n+n^*=N$. Therefore, the location of the marginal consumer who purchase Home hardware is given by a function of n, that is,

$$t(n)=[n^{1/(\sigma-1)}-(N-n)^{1/(\sigma-1)}](e-c)(\sigma-1)/2kb\sigma+1/2. \quad (7)$$

And the first derivative of $t(n)$ is positive:

$$t'(n)\equiv\frac{dt(n)}{dn}=\frac{[n^{(2-\sigma)/(\sigma-1)}+(N-n)^{(2-\sigma)/(\sigma-1)}](e-c)}{2kb\sigma}>0. \quad (8)$$

This means that the share of Home hardware is increasing in the amount of software for it. It can also be shown that

$$t(0)\geq 0 \text{ and } t(N)\leq 1 \quad \Longleftrightarrow \quad N^{1/(\sigma-1)}\leq kb\sigma/[(e-c)(\sigma-1)] \quad (9)$$

and

$$t'(N/2)\geq 1/N \quad \Longleftrightarrow \quad N^{1/(\sigma-1)}\geq 2^{1/(\sigma-1)}kb\sigma/2(e-c). \quad (10)$$

Based on the above, we can draw the function $t(n)$ as shown in Figure 1,[7] where curves A, B, and C correspond to the graph of $t(n)$ under each of the following three cases: in case A, $N^{1/(\sigma-1)}\leq kb\sigma/[(e-c)(\sigma-1)]$; in case B, $kb\sigma/[(e-c)(\sigma-1)] < N^{1/(\sigma-1)} < 2^{1/(\sigma-1)}kb\sigma/2(e-c)$; and in case C, $N^{1/(\sigma-1)}\geq 2^{1/(\sigma-1)}kb\sigma/2(e-c)$.[8]

[7] The second derivative of $t(n)$ is negative (positive) if n is smaller (greater) than $N/2$, since

$$\frac{d^2t(n)}{dn^2}=-\frac{[n^{(3-2\sigma)/(\sigma-1)}-(N-n)^{(3-2\sigma)/(\sigma-1)}](\sigma-2)(e-c)}{2kb\sigma(\sigma-1)},$$

where $\sigma>2$ from the assumption $\theta>1/2$.

[8] The importance of discrimination between case B and C will appear in the following.

Note that in cases B and C, $t(n)$ can reach 0 or 1, even if there are still two types of software. Since the market is of unit length, that is, $0 \leq t \leq 1$, there exists a critical number of software firms for each type of hardware such that if the number of software firms for one technology exceeds the critical number, then all consumers purchase the dominant hardware. On the other hand, in case A, there are two types of consumers unless one hardware is standardized; no software for the other hardware exists.[9]

3.2 Second Stage

In the second stage, software firms simultaneously select the network for which to supply software are. Given the marginal consumer, t, and the number of competing software firms (n or n^*), the profit of a software firm writing software for Home hardware is[10]

$$\pi(t,\ n) = t(p-b)x - f = t(e-c)/n\sigma - f, \tag{11}$$

and that for Foreign hardware is

$$\pi^*(t,\ n^*) = (1-t)(p-b)x^* - f = (1-t)(e-c)/n^*\sigma - f, \tag{12}$$

where $x^* = (e-c)/n^*p$. From these equations, it is easily derived that

$$\pi(t,\ n) \gtreqless \pi^*(t,\ n^*) \quad \Longleftrightarrow \quad t \gtreqless \frac{n}{N}. \tag{13}$$

Based on the latter inequality, each firm considers whether $t(n)$ is greater than n/N or not, and then chooses the network to supply.

3.3 First Stage

At any equilibrium where two networks coexist, $\pi(t,\ n) = \pi^*(t,\ n^*)$ must be satisfied. Therefore, $t = n/N$ holds at the equilibrium and

$$\pi = \pi^* = (e-c)/N\sigma - f. \tag{14}$$

[9] Since we assume that hardware only facilitates the consumption of software and provides no stand-alone benefits, in case A, the marginal consumer, t, changes discontinuously to 0 or 1 when n is equal to 0 or N.

[10] Note that softwares for one country's hardware are produced by firms located in that country. See Footnote 4.

On the other hand, if all software firms provide software for one network at equilibrium, then $(t, n) = (1, N)$ or $(t, n^*) = (0, N)$ hold and

$$\pi = (e - c)/N\sigma - f \quad \text{or} \quad \pi^* = (e - c)/N\sigma - f. \tag{15}$$

Thus, the profit of each firm is independent of equilibrium software configurations, and the free-entry number of firms, N, is uniquely given by $N = (e - c)/f\sigma$ from the zero-profit condition.

Based on the foregoing argument, we can conclude that $\pi = \pi^* = 0$ holds for any pair (t, n) on the dotted line in Figure 1, $\pi = 0$ at $(1, N)$, and $\pi^* = 0$ at $(0, 0)$, while π (π^*) is positive (negative) at any pair above the line and *vice versa*.

3.4 Nash Equilibrium Configurations

Based on the foregoing argument, we obtain the Nash equilibrium configurations as follows: In order for a configuration to be a Nash equilibrium, it must be impossible for a software firm to switch networks and increase its profit.

In case A, the graph of $t(n)$ is drawn as curve A in Figure 1. So, there are three equilibrium candidates; $(n = n^* = N/2)$, $(n = N, n^* = 0)$, and $(n = 0, n^* = N)$. Since

$$t(n) \begin{cases} > n/N & \text{if} \quad n < N/2, \\ < n/N & \text{if} \quad n > N/2, \end{cases} \tag{16}$$

we can conclude that only symmetric equilibrium $(n = n^* = N/2)$ is stable in the sense of a Nash equilibrium.

On the other hand, in case C, the graph is drawn as curve C and

$$t(n) \begin{cases} < n/N & \text{if} \quad n < N/2, \\ > n/N & \text{if} \quad n > N/2. \end{cases} \tag{17}$$

Therefore, only two equilibria, $(n = N, n^* = 0)$ and $(n = 0, n^* = N)$, are stable.[11]

Finally, in case B, the graph of $t(n)$ is drawn as curve B and it is apparent from the discussion above that all three of the equilibria, $(n = n^* = N/2)$,

[11] In the interval of n where $t(n)$ is greater than 1 (smaller than 0), the actual marginal consumer, t, is equal to 1 (0) and is still above (below) the line $t = n/N$.

$(n = N, n^* = 0)$, and $(n = 0, n^* = N)$, are stable. So, we have the following proposition:

Proposition: Depending on the parameter values, the following three cases emerge:
Case A: If $N^{1/(\sigma-1)} \leq kb\sigma/[(e-c)(\sigma-1)]$*, a unique symmetric equilibrium exists,* $(n = n^* = N/2)$*. In this case, intra-industry trade in both hardware and software products occurs between countries.*

Case B: If $kb\sigma/[(e-c)(\sigma-1)] < N^{1/(\sigma-1)} < 2^{1/(\sigma-1)}kb\sigma/2(e-c)$*, three equilibria,* $(n = n^* = N/2)$*,* $(n = N, n^* = 0)$*, and* $(n = 0, n^* = N)$*, exist.*

Case C: If $N^{1/(\sigma-1)} \geq 2^{1/(\sigma-1)}kb\sigma/2(e-c)$*, only two equilibria,* $(n = N, n^* = 0)$ *and* $(n = 0, n^* = N)$*, exist. In this case, no intra-industry trade occurs: one country only imports other country's hardware/software system.*

These cases are summarized in Figure 2. In case A, the degree of hardware differentiation (k) is relatively large and the equilibrium configuration will involve multiple networks. Home consumers located at $1/2 \leq t \leq 1$ switch to buy Foreign hardware and Foreign softwares, while Foreign consumers located at $0 \leq t \leq 1/2$ switch to buy Home hardware and Home softwares. Thus, intra-industry trade in both hardware and software products occurs between countries. In short, this case emphasizes the fact that, given that the indirect network effects are relatively small, trade is driven by product differentiation of (country-specific) hardwares.

Contrast to this, in cases B and C, the equilibrium configuration will most likely be a single hardware/software system. In this case, no intra-industry trade occurs: one country only imports other country's hardware/software system. Given that the indirect network effects are relatively large, trade is driven by demand-side scale economies: one country's hardware (and hence softwares written for that hardware) dominates the international market.

4 Conclusions

In this note, we examine how trade liberalization affects production structure in the presence of indirect network effects. For these purposes we construct a simple two-country model of trade with incompatible country-specific hardware technologies. We show that trade patterns are determined by the interaction between hardware differentiation and indirect network effects due to software availability.

We believe that one benefit of our model is its simplicity: the introduction of indirect network effects in the trade model does not make the exercise intractable. This suggests that we can use this model, and make it more complicated, to answer a certain number of questions. For example, we could analyze the gains/losses from trade liberalization in the presence of indirect network effects.

References

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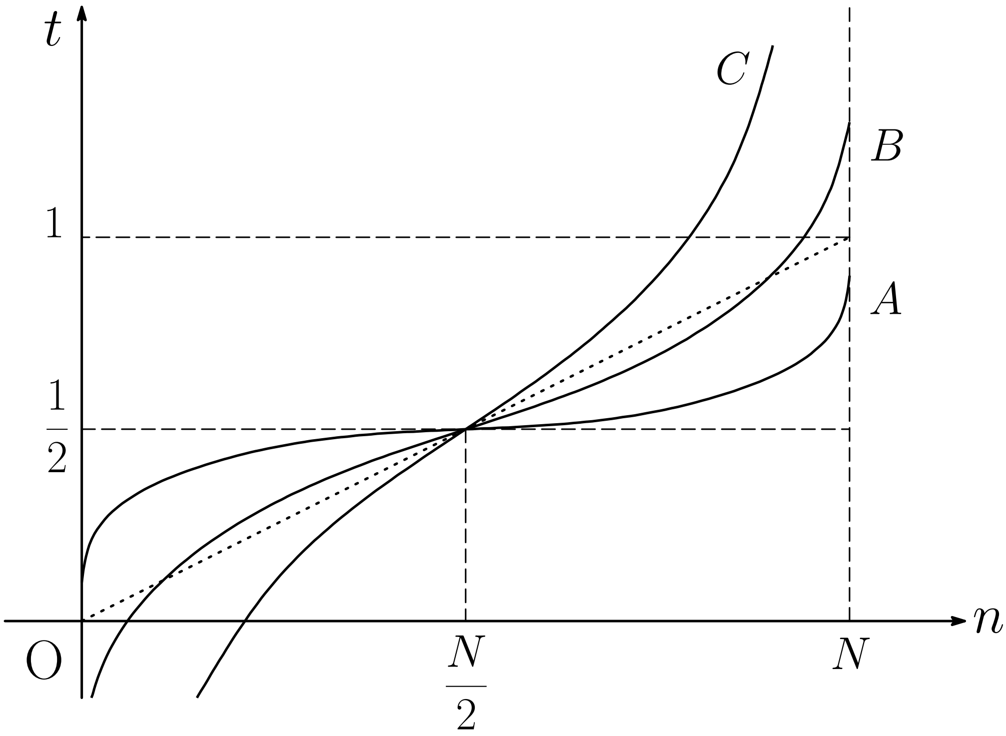

Figure 1

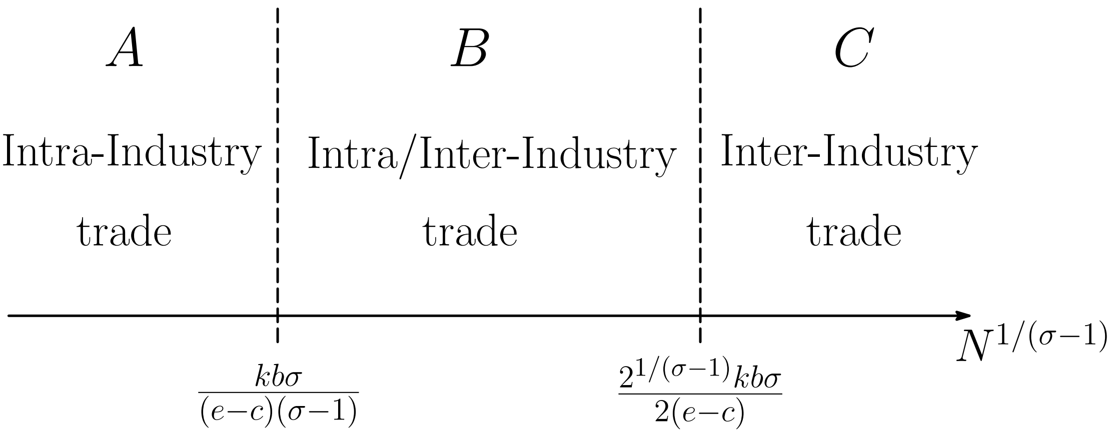

Figure 2