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On Vertical Product Differentiation, Network Externalities and Compatibility Decisions: Existence of Incompatible Networks - An Example

Sumit Sarkar[1]
Indian Institute of Management Kozhikode, Kozhikode
Kerala 673 571

Abstract

Market mechanism may or may not throw up *compatibility* in *markets for systems* where network effect arises due to *complementarity* of component parts of a system. We consider a game, where, in stage 1, the firms decide whether to standardise on a single technological platform or not and at the same time they choose the *quality* of their product. In stage 2, the firms compete in prices. With the help of an example we show that pure-strategy Nash equilibrium may not exist. In that case, there exists a mixed strat-

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Email: sumits@iimk.ac.in

egy equilibrium such that vertically differentiated but mutually incompatible networks co-exist with a strictly positive probability.

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1 Introduction:

It has long been recognised that for some goods and services (e.g., computers, tele-communications, etc.) there exist positive consumption externalities. Since this effect was first observed in industries / markets where there is a physical network, such positive consumption externalities are commonly called network externalities.[2] The very existence of network externality immediately throws up some problems, which directly affect the strategic decisions of firms as well as consumers. The 'technology adoption decision of firms' and the 'product selection decision of consumers' are classic problems in this area. The technology adoption decision of firms primarily revolves around the decision regarding 'product compatibility'. Since achieving compatibility may be costly, market mechanism may or may not throw up compatibility. So, when technology choices are left to the market, firms take up compatibility decision as a strategic variable.

The classical works [Katz and Shapiro (1985, 1986a, b), Farrell and Saloner (1985, 1986a, b) etc.], on compatibility and standardization in presence of network externality, illustrate that markets may fail to maximize social wel-

[2]The terms written in italics in this section are formally defined in the next section.

fare. Converters can exacerbate this problem and also make standardization more difficult. For example, Farrell and Saloner (1992) show that converters reduce the social cost of a failure to standardize by allowing the consumers to break through the barrier that separates one network from another. However, by making it easier for consumers to follow separate technological paths, converters make standardization more difficult.

A striking feature of the existing literature on compatibility is the assumption of homogenous product. Only a few papers focus on strategic product differentiation in markets with network externalities. However, majority of them [Bental and Spiegel (1995), De Palma and Leruth (1996) and Economides and Flyer (1997).] considers network size as the only dimension of product differentiation. The possibility of vertical product differentiation, in terms of intrinsic quality of the good, is largely overlooked.

Only Baake and Boom (2001) incorporated vertical differentiation while modeling compatibility decision in a duopoly market for a network good. In Baake and Boom (2001), the firms simultaneously take decision on two separate aspects - firstly, on quality of the product and secondly, on whether to provide a two-way converter to make the products compatible or not. They find that, in equilibrium, the firms choose different qualities but keep the products compatible.

Baake and Boom (2001) does not explain the existence of incompatible and vertically differentiated networks. It is true that incompatible and vertically differentiated networks are not very common. But there are examples where incompatible and vertically differentiated networks co-existed, at least for some time. In the early 1980s vertically differentiated and incompatible operating systems CP/M and DOS co-existed.[3] Later, DOS became the industry standard. The objective of our paper is to provide an explanation for the existence of incompatible networks in a vertically differentiated market. Like Baake and Boom (2001), we focus our analysis to market for systems. In Baake and Boom (2001) the sub-game perfect equilibrium is such that the firms always differentiate their products vertically but never horizontally. In stark contrast, we find that such equilibrium does not exist for all values of the coefficient of network externality. More importantly, we show that there exists a mixed strategy equilibrium such that vertically differentiated but mutually incompatible networks co-exist with a strictly positive probability.

Our result differs from that of Baake and Boom (2001) due to a difference in framework. Baake and Boom (2001) adopt a framework where the products are based on mutually incompatible technologies and compatibility could be achieved only by provision of a two-way converter. In sharp contrast, in our framework standardization on one technological platform is the only way of achieving compatibility. These two are contrasting frameworks and both are worth considering.

The paper is organized as follows. In section 2 we present some relevant concepts and definitions, we present the example in section 3 and in section 4 we conclude.

[3]DOS was a significantly better quality operating system vis--vis CP/M. For a detailed discussion see Gandal et el. (1999)

2 Concepts and definitions:

2.1 Network externality:

Following Katz and Shapiro (1985), we define network externality as a change in the benefit, or surplus, that a consumer derives from a good when the number of consumers, consuming the same kind of good, changes.

2.2 Systems:

A collection of two or more components [e.g., a durable good (hardware) and a complementary good or service (software)], used together with the help of an interface, forms a system. For instance, computer and programs must be used together to produce computing service.

2.3 Network externality in market for systems:

In a market for systems, where there is no physical network, a consumer's benefit function does not directly depend on the adoption decision of other consumers. In such markets as the sales of hardware of a particular configuration increases, the market may provide a larger variety of software that can run on that class of hardware. Availability of a larger variety of software is a benefit to the consumers. Also, the consumers are likely to enjoy more surpluses in the software market, if software production is subject to decreasing marginal cost. A larger base of hardware owners will lead to larger sales of software and hence lower marginal cost and lowers price of software. Thus a network externality is generated in the market for systems, due to complementarity of component parts of a system.

2.4 Compatibility in market for systems:

A network good generates higher benefits to consumers, if made compatible to another such commodity. To understand the concept let us consider the following example from the market for systems. Two (computer) operating systems are perfectly compatible with each other if any program that can run on one of them can also run on the other. There are two ways in which compatibility may be achieved. One way to achieve compatibility is standardisation and the other is provision of a two-way converter. In market for systems, when the products are standardised, the firms base their products on the same technological platform.[4] On the other hand, a two-way converter is a devise that allows products based on different technological platforms to work with one another.

2.5 Network size in market for systems:

Network size is simply the mass of consumers in a network. If the systems produced by different firms are compatible to each other, then the network size of any of the firms is the mass of consumers covered by the industry. However, if the systems produced by different firms are incompatible to each other, then the network size of a firm is only the mass of consumers covered by that firm.

[4]This term is adopted from literature on computer industry. Loosely speaking, a technological platform is a bundle of standard components

3 The Example:

We consider a market for a system, where two firms, firm A and firm B, produce the hardware. Each firm choose a technological platform, t, from $\{t', t''\}$. The technological platforms, t' and t'' are mutually incompatible, i.e., the products of the two firms are compatible to each other, if and only if they standardise on a single technological platform. Of course there is the possibility of *partial compatibility*, i.e., there exists some software which runs on hardware A as well as on hardware B but not all can be run on both brands of hardware. In this example we assume that the products are either perfectly compatible or they are perfectly incompatible.

The firms, at the same time, choose a quality s. Let $s \in \{1, 2\}$ i.e., the firms can either choose the high quality ($s = 2$) or the low quality ($s = 1$).

We assume that the cost of production is zero for both firms.

There exists a continuum of consumers, who are identical in all respects, except for the fact that, their preferences for the quality differs according to their type. We assume that the consumers are distributed uniformly in $[0, 1]$, according to their type θ. The type of a consumer can be interpreted as her taste parameter, which reflects her willingness to pay for quality. This also implies that the market size is equal to unity.

Each consumer has a completely inelastic demand for one unit of the commodity. The indirect utility derived from consumption of one unit of good i ($i = A, B$) is a function of network size of good I, its quality and its price. The indirect utility function is given by,

$$V_i = 0.5k_i + \theta s_i - P_i \quad (1)$$

where, k_i is the network size of good i.

θ is the taste parameter, θ follows uniform distribution in $[0, 1]$.

P_i is the price of good i.

In stage I, firms simultaneously choose a pair (s, t) from $1, 2 \times (t', t'')$.

In stage II, firms simultaneously choose prices, P_i $(i = A, B)$. There are four possible outcomes at the end of the stage I.

- Firms differentiate their products vertically (in terms of quality) but not horizontally (i.e., standardise on a single technological platform).
- Firms differentiate their products both vertically (in terms of quality) as well as horizontally (in terms of technological platforms).
- Firms choose same quality but differentiate their products horizontally (in terms of technological platforms).
- Firms choose to produce homogenous products (i.e., they choose the same quality and they standardise on a single technological platform).

First, we produce four basic results corresponding to all the four possible outcomes of the stage I.

Result 1: *When the firms differentiate vertically, but not horizontally, in the stage I of the game, there exists a stable interior solution to the posterior price game, with the 'High quality' firm charging a price $P_c^H = \frac{2}{3}$ and the 'Low quality' firm charging a price $P_c^L = \frac{1}{3}$. The profits are 4/9 and 1/9 respectively.*

Proof: In this case the firms standardise on a single technological platform and hence the products are perfectly compatible.

We define θ_c^*: such that the consumer with $\theta = \theta_c^*$ is indifferent between the 'High quality' and the 'Low quality'. For the consumers with $\theta > \theta_c^*$ 'High quality' is preferred to 'Low quality' and for the consumers with $\theta < \theta_c^*$ 'Low quality' is preferred to 'High quality'.

$$q_c^H = 1 - \theta_c^* \tag{2a}$$

$$q_c^L = \theta_c^* \tag{2b}$$

Since the products are perfectly compatible, the network sizes are same for both firms.

$\therefore$ By definition, $\theta_c^* = P_c^H - P_c^L$ (3)

Where, P_c^H is the price charged by the 'High quality' firm and P_c^L is the price charged by the 'Low quality' firm, when they produce compatible products and compete in prices in the stage II of the game.

Substituting from (3) in (2a) and (2b) we get the demands for 'High quality' firm and 'Low quality' firm respectively when the firms produce compatible products and compete in prices in the stage II of the game.

Now from the first order conditions of profit maximization, we get the price reaction functions as,

$$P_c^H = \frac{1+P_c^L}{2} \tag{4a}$$

$$P_{pc}^L = \frac{P_c^H}{2} \tag{4b}$$

Solving the reaction functions we get the equilibrium prices as,

$P_c^H = \frac{2}{3}$

$P_c^L = \frac{1}{3}$

Substituting the equilibrium prices in the profit functions, we get,

$\Pi_{pc}^H = \frac{4}{9}$

$\Pi_{pc}^L = \frac{1}{9}$

Result 2: *When the firms differentiate vertically as well as horizontally in the stage I of the game, the 'High quality' firm monopolizes the market by charging a price* $P_N^H = \frac{1}{2}$. *It earns a profit of (1/2).*

Proof: In this case the firms choose the different technological platform and hence the products are perfectly incompatible.

We define θ_N^*: such that the consumer with $\theta = \theta_N^*$ is indifferent between the 'High quality' and the 'Low quality'. For the consumers with $\theta > \theta_N^*$ 'High quality' is preferred to 'Low quality' and for the consumers with $\theta < \theta_N^*$ 'Low quality' is preferred to 'High quality'.

$$q_N^H = 1 - \theta_N^* \tag{5a}$$

$$q_N^L = \theta_N^* \tag{5b}$$

The indirect utility of a consumer of type θ_N^*, if she purchase from the 'High quality' firm, is given by, $V_H = \frac{1}{2}(1-\theta_N^*)+2\theta_N^* - P_N^H$, and that if she purchase from the 'Low quality' firm is given by, $V_L = \frac{1}{2}\theta_N^* + \theta_N^* - P_N^L$. Clearly, for all values of $\theta_N^* \in [0,1], V_H \geq V_L$, if and only if $P_N^H \leq P_N^L + \frac{1}{2}$ and $V_H < V_L$, if and only if $P_N^H > P_N^L + \frac{1}{2}$. So, the 'High quality' firm monopolizes the market if $P_N^H \leq P_N^L + \frac{1}{2}$ and it leaves the market to the 'Low quality' firm if $P_N^H > P_N^L + \frac{1}{2}$. Price competition will pull down the prices. The 'Low quality' firm cannot undercut price below 0. The 'High quality' firm monopolizes the market by charging a price $P_N^H = \frac{1}{2}$. The full market is covered and the 'High quality' firm earns a profit of (1/2).

Result 3: *When the firms differentiate horizontally, but not vertically, in the stage I of the game there exists an interior solution to the posterior price game where the firms charge zero price and thereby earn zero profits in equilibrium.*

Proof: In this case the firms choose different technological platforms and hence the products are perfectly incompatible. Therefore, they have different networks and the network sizes are equal to their respective market shares. However, the firms choose the same quality, say $s \in \{1, 2\}$.

The indirect utility of a consumer of type θ, purchasing from the Firm $i \in (i = A, B)$ is given by, $V_i = \frac{1}{2}q_i^* + s\theta - P_i^*$, where, q_i^* is the equilibrium demand for the Firm i and P_i^* is the price charged by it in equilibrium.

Now, the consumers of firm A do not gain by deviating iff, $\frac{1}{2}q_A^* - P_A^* \geq \frac{1}{2}q_B^* - P_B^*$. Similarly the consumers of firm B do not gain by deviating iff, $\frac{1}{2}q_B^* - P_B^* \geq \frac{1}{2}q_A^* - P_A^*$. Therefore, both firms have positive sales in equilibrium iff, $\frac{1}{2}q_A^* - P_A^* = \frac{1}{2}q_B^* - P_B^*$.

Now, if any of the firms reduce its price by a small amount ϵ, then every consumer of the rival firm has incentive to deviate. So, both firms have incentive to undercut prices. The firms can undercut till $P_A^* = P_B^* = 0$. Therefore, in equilibrium, both firms earn zero profits.

Result 4: *When the firms produce homogenous products in the stage I of the game, there exists a unique interior solution to the posterior price game, where both the firms charge zero price and hence earn zero profit.*

Proof: Here the firms standardize on a single technological platform and hence the products are perfectly compatible. The network size is equal to the market demand. Also, the firms choose the same quality $s \in \{1, 2\}$. So, the indirect utility of a consumer with taste parameter θ, purchasing from the Firm $i \in (i = A, B)$ is given by, $V_i = \frac{1}{2}(q_A + q_B) + s\theta - P_i$, where, q_i is the equilibrium demand for the Firm i and P_i is the price charged by it in equilibrium.

Now, the consumers of firm A do not gain by deviating iff, $P_A \leq P_B$. Similarly the consumers of firm B do not gain by deviating iff, $P_B \leq P_A$. Therefore, both the firms get positive sales in equilibrium iff, $P_A = P_B$.

Now, if any of the firms reduces its price by a small amount ϵ, then every consumer of the rival firm has incentive to deviate. So, both firms have incentive to undercut prices. The firms can undercut till $P_A^* = P_B^* = 0$.

Therefore, in equilibrium, both firms earn zero profits.

The above stated results summarize the outcomes of the stage II game corresponding to different outcomes of the stage I.

Now we can write the (reduced) stage I game in normal form as follows:

Firm A \ Firm B	$(2,t')$	$(2,t'')$	$(1,t')$	$(1,t'')$
$(2,t')$	$(0,0)$	$(0,0)$	$(\frac{4}{9},\frac{1}{9})$	$(\frac{1}{2},0)$
$(2,t'')$	$(0,0)$	$(0,0)$	$(\frac{1}{2},0)$	$(\frac{4}{9},\frac{1}{9})$
$(1,t')$	$(\frac{1}{9},\frac{4}{9})$	$(0,\frac{1}{2})$	$(0,0)$	$(0,0)$
$(1,t'')$	$(0,\frac{1}{2})$	$(\frac{1}{9},\frac{4}{9})$	$(0,0)$	$(0,0)$

Clearly there does not exist any pure strategy Nash equilibrium in the (reduced) stage I game. In mixed strategy equilibrium, each firm chooses $(2,t')$ with probability (17/38), $(2,t'')$ with probability (17/38), $(1,t')$ with probability (1/19) and $(1,t'')$ with probability (1/19). This example shows that vertically differentiated but incompatible networks exist with a strictly positive probability.

4 Conclusion:

Baake and Boom (2001) show that in a vertically differentiated duopoly market characterizes by presence of network externality, there exists a sub-game perfect equilibrium where the firms differentiate vertically but not horizontally. In contrast, we find that vertically differentiated, but incompatible networks may co-exist with a strictly positive probability. Our result differs from that of Baake and Boom (2001) due to a difference in framework. In

Baake and Boom (2001), in stage I the firms simultaneously choose qualities and in stage II they simultaneously decide on the provision of the two-way converter. As a result one of the firms chooses the highest possible quality, in equilibrium, and the other firm chooses an optimal difference in quality to induce the 'High quality' firm to agree on the provision of the converter. In contrast, in our example, compatibility could be achieved only if the firms standardize on a single technological platform. Here the firms simultaneously choose quality and technological platform. Given the parametric specifications of our example, the monopoly profit is larger than the duopoly profit of the 'High quality' firm. Therefore the 'High quality' firm gains by choosing a different technological platform vis--vis that of the 'Low quality' firm. But the 'Low quality' firm gains by choosing the same technological platform as the 'High quality' firm. As a result there does not exist a pure strategy Nash equilibrium. However, the game being finite, there exists a mixed strategy Nash equilibrium. This implies that incompatible and vertically differentiated networks may co-exist with a strictly positive probability. If, ex-post, the firms differentiate their products vertically as well as horizontally, the 'Low quality' firm gets zero sales. Our example is based on a static model. But intuitively it could be said that in a dynamic framework, the 'Low quality' firm will make an exit from the market and the technological platform adopted by the 'High quality' firm will become the industry standard. The example of CP/M and DOS justifies this claim. In early 1980s CP/M-86 was the de facto industry standard and was sponsored by multiple firms. Even after DOS was introduced CP/M was there in the market. Gradually it was forced to make an exit.

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