Institut für
Volkswirtschaftslehre
und Statistik

No. 612-04

Price Competition and Product Differentiation when Goods have Network Effects

Klaus Conrad

Department of Economics
Discussion Papers

Universität Mannheim
A5, 6
D-68131 Mannheim

Price Competition and Product Differentiation when Goods have Network Effects

Klaus Conrad
University of Mannheim

Abstract

The objective of our approach is to develop a model which captures horizontal product differentiation under environmental awareness, product innovation under network effects, and price competition whereby environmentally friendly products are costlier to produce. As an example, we refer to automobile producers, offering cars with a gasoline powered engine and one with a natural gas powered engine. The network of petrol stations provide the complementary good. The fulfilled expectation equilibrium could be one with either the firm offering the conventional engine as the only producer, or one with the firm offering the new technology as the only producer, or one where both firms share the market. Which equilibrium will emerge depends on the cost of producing energy efficient engines and on environmental awareness of the consumers. Due to the latter aspect the innovative firm has a chance to enter the market. We use a two stage game in prices and characteristics to analyse the respective market structure. We show that if environmental awareness is strong, the firm with the conventional technology will improve energy efficiency of its product. If the network effect is weak, both firms will be in the market. Prices and profits will decline if the role of the network effect becomes important.

Keywords: Price competition; Quality competition; Environmental awareness; Network effects; Automobiles.

JEL classification: L 11, Q 38, H 23 ; L 62

04.05.2004

University of Mannheim, Department of Economics, L7, 3-5, D-68131 Mannheim
Tel.: +49 621 181 1896, Fax: +49 621 181 1893, e-mail: kconrad@rumms.uni-mannheim.de

1. Introduction*

There are many goods for which the utility that a user derives from consumption of the good depends upon the number of other agents buying the good. Industries which are characterized by the existence of those network externalities include the computer industry, the telecommunications industry, the consumer electronics industry (video cassette recorders, compact disc players, etc.) or the automobile industry (repair and gas stations). For products of these industries the value of consuming a particular good increases in the number of consumers (the installed base) who have already purchased the good. Networks exhibit positive consumption and production externalities. A positive consumption externality (or network externality) signifies the fact that the value of a unit of the good increases with the expected number of units to be sold. Depending on the network, the externality may be direct or indirect. The source of a positive consumption externality could be a direct physical effect (e.g. the telephone or fax network) or may be generated through indirect effects (e.g., the number of personal computers and the amount and variety of the complementary good software)[1]. For a durable good like an automobile, for example, consumption externalities arise when the availability of postpurchase service for the good depends on the size of the service network. The number of units of the good that are sold will depend on the service network which, in turn, will increase if more goods have been sold (e.g. foreign car producers entering the car market). Network externalities arise out of the complementarity of different network pieces. The value of a good increases as more of the complementary good is provided (sold), and vice versa. When buying consumer durables, the buyer sometimes prefers well-known brands because of their dense service network. Also the market share as an indicator of product quality and confidence can be interpreted to have the effect of a network (the "word of mouth" effect).

Our example throughout the paper will be the market for natural gas powered cars. Sales will be initially retarded or blocked by consumers' awareness of the thin network of service stations offering natural gas. The scope of the relevant network that gives rise to the consumption externality is identical to the number of already existing petrol stations. The feature of this market is that cars with different engines may use the same network. However, the owner of a natural gas powered car will find a very thin service system since only a few

* I am grateful to Oz Shy for valuable comments on a former version of this paper. I thank the participants of the session of the Ausschuss für Umwelt- und Ressourcenökonomik at St. Gallen, 30.04./01.05.2004 for helpful comments.

[1] See Katz and Shapiro (1985, 1992) and Economides (1996) for more examples.

petrol stations are equipped with natural gas pump posts. This small network will reduce his initial willingness to pay for such a motor vehicle.

The interest in a new kind of fuel (natural gas, hydrogen) for cars or in a new technology (fuel cells) arises from the concern about global warming and the scarcity of fossil fuel. CO_2 emissions could be (partly drastically) reduced by gas-driven cars (natural gas, methane, compressed natural gas (CNG)), by hydrogen powered cars or by a fuel-cell engine system. The fuel-cells are the technology for the distant future. They convert natural gas, methanol or hydrogen fuel into electricity without combustion. When the fuel is hydrogen, then water vapour is the only by-product from the fuel cell itself.[2] It will take about eight years before fuel-cell powered cars are available commercially, and maybe another eight years before they become affordable due to mass production. The true time period will depend, however, on the consumption externality in terms of the network of service and filling stations.[3] To overcome the network problem, most car manufacturers produce bi-fuel powered cars. The disadvantage of these cars is the reduction of space for the backseats and for luggage, which is needed for the two tank fillings.

Hydrogen powered cars are even more environmentally friendly than gas powered cars, but driving with hydrogen is more expensive than with gasoline, given the current price of gasoline. Research institutes, governments and the European Union have started an initiative to develop hydrogen powered cars which are supposed to replace the gasoline powered cars by 2025. The background of this initiative is the assumption that the price of oil will increase due to higher costs of exploration of the scarcer becoming exhaustible resource. Besides the expected price increase of oil, the other reason for a switch to hydrogen is global warming.[4] As in the case of the gas powered engine, the technique is not the problem, the problem is the network.[5]

The objective of the paper is to investigate a market for cars with conventional engines versus cars powered by natural gas or hydrogen. These technologies are subject to indirect network externalities generated by the availability of filling stations that carry the appropriate

[2] But one must consider how the hydrogen gets produced. If it is produced from natural gas (as most hydrogen is) then carbon dioxide is released to the atmosphere in the production of the hydrogen.

[3] One advantage of gas powered cars versus gasoline powered ones is their environmental record and energy bill. From burning methane, emissions of all air pollutants will be lower; CO_2 emissions by 25 percent and the summer smog causing reactive carbon-hydrate are down up to 80 percent. The milage of 25 kilogram methane is 360 km and the costs for that distance € 15 (61 cents per kilogram, tax reduced till 2009). For a gasoline driven car the cost for this distance is about twice as high. However, the price of a gas powered car is about € 2000 higher than for its gasoline power version.

[4] Hydrogen is produced from renewable or non-exhaustible resources like biomass, wind or solar energy. Whereas a gasoline powered car emits 160 gr. CO_2 per km, a hydrogen driven car would emit only 35 gr. CO_2 per km if hydrogen is produced from a non-exhaustible resource.

[5] Hydrogen is filled as a liquid at a temperature of –253° C in a special tank.

type of fuel. Two competing firms choose simultaneously and independently from each other their technology, that is their locations in a horizontal product differentiation dimension on the unit interval. This location also corresponds to how environmentally friendly a product is. Environmentally friendly products are more costly to produce and the cost increases in direct proportion to the product's location on the unit interval. We are interested in the case where the innovative firm offers an entirely environmentally friendly product located at the upper endpoint of the interval and consider the parameter restrictions that yield such an outcome. Consumers differ in their preferences for the product attributes but they all share the same preference concerning the environmental aspect of the product. The product characteristics as well as the environmental quality are measured on the same unit interval, i.e. a certain product characteristic is associated with a unique environmental quality.

In order to relate our findings to the existing literature, we should point out that there are two types of product differentiation – horizontal product differentiation within the same quality group and vertical product differentiation in terms of different quality levels. Horizontal product differentiation emphasizes the fact that the supply of a product variant (within this quality group) does not satisfy completely some or many consumers. It could therefore be a profit maximizing strategy to offer modifications of a standard product which is closer to the preferences of some customers. Under vertical product differentiation firms choose a high or low quality class in the product space.[6] There is a price-quality competition with a trade-off in higher prices for better quality or a lower price for the lower quality. In either of these product differentiation models the firms will choose distinct characteristics or qualities because as those become close, price competition between the increasingly similar products reduces the firms' profit. However, product differentiation causes costs of heterogeneity in terms of time, quality, advertising, and invention of new characteristics. In vertical product differentiation models with environmental background, the focus of environmental policy is often on minimum quality standards (see, e.g. Crampes and Hollander, 1995; Ronnen, 1991; Motta and Thisse (1999)).[7] In Arora and Gangopadhyay (1995), all consumers value environmental quality and have identical preferences but differ in their income levels and hence in their ability to afford a cleaner environment. In Lombardini-Riipinen (2003) a unit emission standard is introduced into the model of vertical

[6] See Gabszewicz and Thisse (1979) or Shaked and Sutton (1982) for typical models of vertical product differentiation.

[7] Crampes and Hollander (1995) have shown that when setting a minimum quality standard, the firm, producing the lower quality, will gain and the high-quality firm will lose profits. Ronnen's (1991) result is that implementing a quality standard narrows the quality gap between firms and brings about a more intensive competition in prices.

differentiation by Arora and Gangopahdyay.[8] Cremer and Thisse (1999) use a vertical differentiation model in which the free entry equilibrium results in an under-provision of quality. Moraga-Gonzalez and Padron-Fumero (2002) examine in a duopoly model with vertical product differentiation the impact of various environmental policy instruments on aggregate emissions and social welfare where consumers are willing to pay more for less polluting variants. Bansol and Gangopadhyay (2003) study the welfare implications of various tax-subsidy policies in an imperfectly competitive market in the presence of environmentally aware consumers. They use a vertically differentiated model with consumers willing to pay more for environmentally superior products. Greaker (2003) presents a partial trade model with one domestic and one foreign firm where products are differentiated along both environmental quality (vertical differentiation) and taste/eco-label (horizontal differentiation). He focuses on horizontal differentiation by assuming that the taste parameter is relatively more important for the consumer than the environmental performance of the product. In his model the two firms are located at each end of the $0-1$ product line whereas in our model location is endogenous for one firm. We follow Greaker by also assuming that horizontal differentiation (environmental concern) dominates vertical differentiation (horse power).

There is a substantial amount of literature on network externalities, see for example Katz and Shapiro (1985, 1986, 1992, 1994), Farrell and Saloner (1985, 1986), Matutes and Régibeau (1996), and especially the book by Shy (2001) devoted to this topic. These authors do not use, however, the models of horizontal or vertical product differentiation. Katz and Shapiro (1985) consider a model of static oligopolistic competition with network externalities. Consumers form exogenous expectations on the network size of the competing firms on the market (as they will do in our model). Then firms determine their prices on which consumers base their purchase decision. The structure of the equilibria confirms the importance of consumers' expectations in markets where network externalities are present. Given the possibility of multiple equilibria in their model (as well as in our model) when products are incompatible, firms' reputations may play a major role in determining which equilibrium actually occurs. Farrell and Saloner (1986) analyze the incentives for adopting a new technology that is incompatible with the installed base. In an equilibrium the outcome depends on the size of the installed base when the new technology is introduced, it depends on how quickly the network benefits of the new technology are realized, and on the relative

[8] Whereas Arora and Gangopahdyay assume that consumers with the lowest taste for environmental quality do not purchase the differentiated commodity, Lombardini-Riipinen includes the welfare of those consumers who did not buy the product before the policy invention and come to the market thereafter.

superiority of the new technology.[9] Our results conform with their results although we use a different model. The parameter space in their as well as in our model, representing attributes, can be divided into three regions. In the first one, the unique perfect Nash equilibrium is characterized by the adoption of the new technology; in the second one the new technology is not adopted; and in the third one, both these outcomes occur in an equilibrium. Their model is dynamic, however, whereas our model is not. Finally, a model similar in spirit is Grilo, Shy and Thisse (2001). They examine a model of horizontal product differentiation that introduces a consumption externality. Unlike the present paper, Grilo et al. exploit a quadratic externality function. This allows them to consider both positive and negative consumption externalities. Another strand of the literature on network economics utilizes an approach sometimes referred to as the supporting services approach. Software packages, for example, are regarded as supporting services for the hardware. The literature utilizing the supporting services approach includes Chou and Shy (1990, 1993) and Church and Gandal (1992 a, b, 1993 and 1996). Like in our car engine case, in many instances supporting services are incompatible across brands. Since a hydrogen powered car must be gasstation compatible, we can not utilizes these models for our case because they compare equilibrium profits and welfare under compatibility and incompatibility.

The paper is organized as follows. In Section 2 we present the model in the case of two firms competing for customers when network effects are present. Section 3 characterizes the conditions for possible market structures. Section 4 concludes.

2. The Model

Our non-cooperative game considers two stages: In the first stage the firms simultaneously choose their respective characteristics. In the second stage firms compete in prices taking into account the degree of product differentiation. Firm 1 decides to produce the conventional gasoline powered engine whereas firm 2 intends to produce a hydrogen powered engine, i.e., we assume that the product embodying technology 1 is already in use when our analysis begins at time zero. In contrast, the "sponsor"[10] of technology 2, firm 2, chooses time zero to introduce its new product to the market. We assume that it is possible for firm 1 to bring out improved versions of its technology, and that firm 2 can introduce only a single version of its

[9] A model on the automobile market based on the approach by Farell and Saloner (1986) has been outlined by Sartzetakis and Tsigaris (2000).

[10] Katz and Shapiro (1986) call a firm a sponsor of a technology if it controls the property rights to a given technology. In that case the firm will be willing to invest into the network or in the form of penetration pricing to establish the technology because then there is the prospect of profits in later periods.

technology.[11] Firm 2 is convinced that environmental concern and the prospect of running out of oil in the near future is a good reason to offer cars with this new technology. Therefore firm 2 will produce the characteristic at the upper end of the zero-one characteristic line. Firm 1 adheres to the conventional technology but will use its option to vary its technology in terms of gasoline efficiency. Depending on environmental concern and cost aspects it will choose characteristics within the [0, 1] interval. Both firms include installed base considerations. The network of gasoline stations is exogenous to the firms and they know about consumers' awareness of the compatibility of an engine with a filling station. Our model differs from standard models of product differentiation because of the introduction of a network externality and of consumers' awareness of a negative externality. The network externality enters the game as a buyer will favour the product owned by many to the product (the new technology) owned by few. As mentioned before, usually a large number of owners of the same good (a motor vehicle) will ensure a broader supply of complementary goods (gasoline station or natural gas stations) than is the case with a smaller number of owners. Compatibility of the new product of firm 2 with the installed base of firm 1 is not a meaningful strategy as it is for a PC producer offering an IBM compatible PC which can use the standard software.[12] A natural gas powered car is not compatible with the existing network of gasoline stations.[13]

Consumers base their purchase decision on prices, product differentiation (gasoline consumption and environmental characteristics), and on the network effect. Consumers' awareness is the negative externality caused by traffic such as air pollution from CO_2 and NO_X emissions. As a characteristic q of the good which affects the willingness to pay of a potential customer, we consider different types of engines within a quality class of motor vehicles. The characteristic of the consumer, described by $\theta \in [0,1]$, is the interest in energy related attributes of a car, which is the reason for the different willingness to pay. Some consider gas-guzzlers as a comfortable car although they are extreme environmentally unfriendly, while others care about an environmentally friendly technology like fuel cells

[11] At the end of this section we will derive an interval of parameters for environmental (energy efficiency) and cost trade-off such that offering hydrogen driven cars is a rational strategy.

[12] See Pfähler and Wiese (1998) for a game in the degrees of compatibility. For a survey on compatibility and network effects see Wiese (1997).

[13] We exclude the strategy to produce cars with bi-fuel engines, having two tanks. This strategy, observable in reality, is a way to become compatible with the installed base. Although it would eliminate the advantage of the installed base of the competitor it raises the cost of production and in addition reduces the capacity of the trunk compartment. Instead of adding another stage to the game where firms simultaneously decide upon the compatibility of their products, then on quality and finally on prices, we could interpret a car close to the right end of the product line to be equivalent to a bifuel car. For the consumer, partial compatibility is offset by the reduced space of the trunk compartment.

although they have asymmetric information with respect to the property and reliability of this technology. There is a continuum of consumers uniformly distributed over Hotelling's [0, 1] interval. Each consumer buys one unit of the product. Products localized to the left are characterized by aspects linked to fuel inefficiency like horse power and driving dynamics, and products to the right by stillness in running, by a low noise gauge of the engine and by a jerk-free start and a more comfortable stop and go driving. In such a model of horizontal product differentiation we do not assume that if $q_2 > q_1$ and prices are equal, all consumers purchase the environmentally more friendly car with q_2. Some consumers prefer automatic transmission (which needs more fuel), a better initial velocity, they enjoy the noise of the engine and its driving dynamics. That is, we assume that the difference in the willingness to pay, $u(q_1,\theta)-u(q_2,\theta)$ if product characteristics q_1 and q_2 differ, is positive for some consumers and negative for others. The net-utility of consumer $\theta \in [0,1]$ for a unit of the good of quality q_1 is defined by

(1) $$v(q_1,\theta) = r - t(q_1-\theta)^2 - d(1-q_1) - p_1 + \gamma \cdot n_1(\tau)$$

in which *r* stands for the gross, intrinsic utility a consumer derives from consuming one unit of the product.[14] The term $t(q_1-\theta)^2$ represents the costs a consumer, located at $\theta \in [0,1]$, bears if he does not get his preferred characteristic because he buys from firm 1 selling characteristic q_1. His ideal car within the class of middle sized family cars is θ but firm 1 offers q_1. The parameter *t* expresses the strength of personal preferences. It can be normalized to 1 in the gross utility term (the term without the price) without loss of generality. With $d \cdot (1-q_1)$ we express the awareness of a negative externality caused by the product, i.e. environmental concern. It is modelled as a bad conscious of not having purchased the most energy efficient and hence environmentally friendly product at the end of the quality line [0, 1]. We therefore incorporate environmental concern directly into individual preferences.[15] The term $d(1-q_1)$ is a money-metric measure of the cost of negative externalities from fuel consumption. When $q_1 = 0$, then *d* represents the highest money-metric disutility from emissions (environmental damage) including excessive fuel consumption. When $q_1 = 1$, there

[14] In the tradition of spatial models of product differentiation, it is assumed that *r* is sufficiently large to ensure that all consumers prefer buying rather than dropping out of the market.
[15] See Conrad (2002) for a model with care for the environment.

is no money-metric disutility because the consumer has decided in favour of the most environmentally friendly and efficient technology.[16] The term $d\left(1-q_1\right)$ could also be interpreted in the following sense. If a car to the left has more horse power, then everybody will prefer it, so the quality part could be written as $\overline{t}\left(1-q_1\right)$, and the environmental part as $-\overline{d}\left(1-q_1\right)$ (the "warm glow" effect). We do not separate the two but assume that in $\left(\overline{t}-\overline{d}\right)\left(1-q_1\right)$ with $d:=\overline{t}-\overline{d}$ the environmental concern dominates the horse power quality aspect (which in principle is vertically differentiated). That is, we focus on horizontal product differentiation by assuming that the environmental parameter is relatively more important to the average driver than the horse power quality aspect. The fuel bill is taken into account by defining *r* as a net intrinsic utility adjusted for fuel costs. The difference in fuel consumption is captured by $d\left(1-q_1\right)$.

The price of firm 1 is p_1 and the term $\gamma \cdot n_1\left(\tau\right)$ is the network benefit for good 1 where τ is the expected market share of firm 2, i.e. $n_1\left(0\right)=n$ at the beginning, *n* as the total number of customers. Network benefits enter consumers' utility and they are willing to pay for that. The size of the network benefit is modelled as a product of the strength of the network effect γ and its size $n_1(\tau)$. The higher γ, the more important is the network. Since $n_1+n_2=n$, $n_2\left(\tau\right)$ are the customers of firm 2 $\left(n_2\left(0\right)=0\right)$. The network benefit for firm 1 decreases, i.e. will become less important when the number of consumers $n_2\left(\tau\right)$, connected to the competing network of good 2, increases. Hence, the utility that a given user derives from the good depends upon the number of other users who are in the same network as is he. All *n* consumers have bought the product of firm 1 in the past. Its characteristic could have been $q_1=0$ whereas firm 2 considers to produce only the new, energy efficient product, i.e. $q_2=1$. This maximal horizontal product differentiation at the $0-1$ end points of the Hotelling line is the outcome of the standard Hotelling model without environmental concern and network effects. Later on we will derive the parameter constellations under which maximal horizontal differentiation is a Nash equilibrium and under which one $q_1>0,\ q_1=1$ is an equilibrium of the two stage game in price and quality competition. The net-utility of a customer when buying a unit from firm 2 is:

---

[16] In (1) θ is no longer "the bliss point" of the consumer, as in conventional horizontal product differentiation models. The FOC of (1) with respect to q_1 yields $\theta+\dfrac{d}{2t}$ as the bliss point.

(2) $$v(q_2,\theta) = r - t(q_2-\theta)^2 - d(1-q_2) - p_2 + \gamma\, n_2(\tau).$$

Even if the attribute is highly esteemed (e.g. $q_2 = 1$) and the good not expensive, the innovative firm might be unsuccessful because the installed base does not exist. After the outcome of the game, all *n* customers will be served. As $n_2(0)$ is zero or very small at the beginning, the network benefit term represents the aspect that when introducing a new technology, the first question that comes to mind is whether the new technology will be adopted given the large installed base (i.e. $n - n_2$) of the existing technology.

As an example, let firm 1 produce gasoline powered cars (GPC) and firm 2 natural gas powered cars (NGPC). At the beginning of the market game, all households own a GPC. Let us for the time being assume that firm 2 can only produce cars with $q_2 = 1$ whereas firm 1 can improve fuel efficiency of GPC by raising q_1 from $q_1 = 0$ (10 ltr./100 km) to $q_1 = 0.5$ (6 ltr./100 km) or finally towards $q_1 = 1$ (3 ltr./100 km). In the case of $q_1 = 1$, households are indifferent in terms of the property of fuel efficiency of cars. The difference of the net-utilities in (1) and (2) shows the possibilities, firms have for attracting customers:

(3)
$$\begin{aligned} v(q_1,\theta) - v(q_2,\theta) = {} & \underbrace{p_2 - p_1}_{\text{price effect}} \underbrace{- t\left[(q_1-\theta)^2 - (q_2-\theta)^2\right]}_{\text{horizontal product differentation}} \\ & \underbrace{-d\cdot(q_2 - q_1)}_{\text{image concern}} + \underbrace{\gamma\left(n_1(\tau) - n_2(\tau)\right)}_{\text{network effect}} \end{aligned}$$

Firm 1 can increase or keep its market share by a price advantage, by product differentiation, by taking into account environmental concern of consumers, and by the difference of the size of the network. Whereas firms can determine price and quality, they can not influence the network advantage which comes from the installed base in the past and from expectations on demand and on compatibility.

The network situation at the beginning is characterized by the fact that the network of GPCs (gasoline station, repair shops) is sufficient, but there is no network for NGPCs. The situation is characterized by non-compatibility between products in the sense that each firm continues to produce according to its own technology, but the products (cars) of the two firms can not use the same service installation. For products with network effects, expectations play a central role because the vigour of the network depends on the expected future market share and on the market share in the past. In order to determine the expected market share we assume that consumers have rational expectations; i.e. they expect the market share which will result at the end of the competitive process. [17] In such a fulfilled expectation equilibrium it is:

(4) $$n_1\left(1-\hat{\theta}\right)=n\cdot\hat{\theta} \qquad n_2\left(1-\hat{\theta}\right)=n\cdot\left[1-\hat{\theta}\right],$$

where $\hat{\tau}=\left(1-\hat{\theta}\right)$ is the expected market share of firm 2 (consumers to the right of $\hat{\theta}$) and $\hat{\theta}$ is the expected market share of firm 1 (consumers to the left of $\hat{\theta}$) and by $\hat{\theta}$ we denote the critical consumer who is indifferent between consuming q_1 or q_2.

We are interested in finding a consumer $\hat{\theta}\in\left(0,1\right)$ who is indifferent at prices p_1, p_2 to purchase from producer 1 (to the left of $\hat{\theta}$) or from producer 2 (to the right of $\hat{\theta}$). From $v\left(q_1,\hat{\theta}\right)=v\left(q_2,\hat{\theta}\right)$ and the condition, that the networks, expected by the consumer, are the actual networks, i.e. (4), we can solve for $\hat{\theta}$ to get firm 1's specific demand function $D_1\left(p_1,p_2\right)=\hat{\theta}$:

(5) $$D_1\left(p_1,p_2\right)=\hat{\theta}=\frac{p_2-p_1+\left(q_2-q_1\right)\left[q_1+q_2-d\right]-\gamma\cdot n}{2\left(q_2-q_1\right)-2\,\gamma\,n}$$

where t has been set equal to 1. In this comparative static analysis we assume that an equilibrium emerges after a certain period of time. We do not describe the market process which might lead to the following three types of equilibrium market structure:

a) $\hat{\theta}=1$, $1-\hat{\theta}=0$ (market exit of firm 2)

b) $\hat{\theta}=0$, $1-\hat{\theta}=1$ (market exit of firm 1)

c) $0<\hat{\theta}<1$, $1>1-\hat{\theta}>0$ (both firms share the market).

[17] When network externalities exist, consumers must form expectations regarding the size of (competing) networks. Katz and Shapiro (1985) use a notion of fulfilled expectation equilibrium. For some set of expectations only one firm will produce output, while for other sets of expectations there will be both firms in the market. At a market equilibrium of the simple single-period world, expectations are fulfilled $\left(n=n^e\right)$.

Our objective is to characterize the quality choices and pricing policies which would be consistent with these three types of market structure. Case a) chracterizes a market structure where firm 1 has defended its leading position. All customers still buy the GPC at energy efficiency q_1^*. Case b) describes the situation where firm 1 has been driven out of the market and firm 2 serves the whole market. Case c) characterizes a market structure where firm 2 has captured $100 \cdot \left(1-\hat{\theta}\right) > 0$ percent of the total market.

The demand function for firm 2 is

(6) $$D_2\left(p_1, p_2\right) = 1-\hat{\theta} = \frac{p_1 - p_2 + \left(q_2 - q_1\right)\left[2 + d - q_1 - q_2\right] - \gamma\, n}{2\left(q_2 - q_1\right) - 2\,\gamma\, n}.$$

We observe that the price response of market demand is higher if there is a network effect. A marginal decrease of firm 1's price raises its demand by $1/2\left(q_2 - q_1\right)$ if $\gamma = 0$, but by the higher factor $1/\left[2\left(q_2 - q_1\right) - 2\,\gamma\, n\right]$ under network effects. Demand is raised by the non-network term which raises expectations of a higher market share. This in turn raises demand beyond the factor $1/2\left(q_2 - q_1\right)$.

In producing the two characteristics we assume that costs increase in *q*. The costs of production are higher for a producer of family-sized middle class cars if he offers an engine with about the same horsepower but with a better fuel efficiency. By backward induction, firms maximize profit with respect to price:

(7) $$\pi_1 = p_1\, n_1 - c\, q_1\, n_1 = n\left(p_1 - c\, q_1\right)\cdot \hat{\theta}\left(p_1\;\, p_2\right)$$

and

(8) $$\pi_2 = p_2\, n_2 - c\, q_2\, n_2 = n\left(p_2 - c\, q_2\right)\cdot \left(1-\hat{\theta}\left(p_1, p_2\right)\right).$$

A Nash equilibrium in prices can be derived from $\frac{\partial\, \pi_1}{\partial\, p_1} = 0, \quad \frac{\partial\, \pi_2}{\partial\, p_2} = 0$. The reaction functions are

(9) $$p_1\left(p_2\right) = \frac{1}{2}\left\{p_2 + \left(q_2 - q_1\right)\left[q_1 + q_2 - d\right] - \gamma\, n + c\, q_1\right\}$$

(10) $$p_2(p_1) = \frac{1}{2}\left\{ p_1 + (q_2 - q_1)[2 - q_1 - q_2 + d] - \gamma\, n + c\, q_2 \right\}.$$

The benefit of the network shifts the positively sloped reaction functions of both firms outwards and hence increases price competition. The Nash-equilibrium in prices $\left(p_1^*, p_2^*\right)$ is:

(11) $$p_1^* = \frac{1}{3}\left[(q_2 - q_1)[2 + q_1 + q_2 - d] - 3\,\gamma\, n + c\left(q_2 + 2\, q_1\right)\right]$$

(12) $$p_2^* = \frac{1}{3}\left[(q_2 - q_1)[4 - q_1 - q_2 + d] - 3\,\gamma\, n + c\left(q_1 + 2\, q_2\right)\right]$$

Under price competition, the network effect lowers the equilibrium prices of both firms.

Finally, the equilibrium market share follows from (5) by inserting p_1^*, p_2^* from (11) and (12):

(13) $$\theta^*(q_1, q_2) = \frac{(q_2 - q_1)[2 + q_1 + q_2 - d] - 3\,\gamma\, n + c\left(q_2 - q_1\right)}{6\left[(q_2 - q_1) - \gamma\, n\right]}.$$

Similarly, from (6):

(14) $$1 - \theta^*(q_1, q_2) = \frac{(q_2 - q_1)\left[4 - (q_1 + q_2 - d)\right] - 3\,\gamma\, n - c\left(q_2 - q_1\right)}{6\left[(q_2 - q_1) - \gamma\, n\right]}.$$

The second order condition of the profit maximization problem in (7) postulates that the denominator in (13) must be positive.

Before we interpret prices and market shares for our three cases a) - c), we analyse the quality game at the first stage of our two-stage game. As mentioned at the beginning, we want a situation where firm 2 has committed to $q_2 = 1$, i.e. either it produces NGPCs or it does not produce at all. Only firm 1 has the option to vary q_1 in terms of fuel efficiency. In order to get a subgame perfect equilibrium in the quality choices q_1 and $q_2 = 1$, we let firm 2 choose its optimal response to q_1. With a Nash equilibrium in qualities, we will set cost and environmental aspects (i.e. c and d) such that $q_2 = 1$.

The problem of firm 1 is:

$$\max_{q_1} \quad \pi_1(q_1,q_2) = \left[p_1^*(q_1,q_2) - c\, q_1 \right] n \cdot \theta^*(q_1,q_2)$$

If an interior solution exists, then q_1^* follows from $\frac{\partial \pi_1}{\partial q_1} = 0$. The FOC is

(15) $$3\,q_1^{*2} + q_1^*\left(-4\,q_2 + 2 - (d-c) + 4\,\gamma\, n\right) + q_2^2 - q_2\left(2 - d - c\right) + 2\,\gamma\, n\left(1 - (d-c)\right) - \gamma\, n = 0$$

Hence we have to solve a quadratic equation in q_1^*.

Similarly, the problem of firm 2 is:

$$\max_{q_2} \quad \pi_2(q_1,q_2) = \left[p_2^*(q_1,q_2) - c\, q_2 \right] \cdot n \cdot \left(1 - \theta^*(q_1,q_2)\right).$$

Again, if an interior solution exists, then q_2^* follows from $\frac{\partial \pi_2}{\partial q_2} = 0$. The FOC is

(16) $$-3\,q_2^{*2} + q_2^*\left(4\,q_1 + 4 + d - c + 4\,\gamma\, n\right) - q_1^2 - q_1\left(4 + d - c\right) - 2\,\gamma\, n\left(3 + d - c\right) + 2\,\gamma\, n = 0.$$

By adding up equations (15) and (16), it is possible to find the following Nash-equilibrium in qualities:

(17) $$q_1^* = -\frac{1}{4} + \frac{d-c}{2} \quad , \qquad q_2^* = \frac{5}{4} + \frac{d-c}{2}.$$

Several other pairs of solution did not satisfy either the restriction $\gamma > 0$, or the denominator in θ^* became zero for the q_1, q_2 pair.[18] For an interior solution $q_1^* \geq 0$ and $q_2^* \leq 1$, $d-c$ should be $\geq 1/2$ and $\leq -1/2$. There is therefore no interior solution. Since we wish that firm 2 offers only energy efficiency $q_2^* = 1$, this assumption is consistent with the assumption $d - c \geq -1/2$. If even $d - c \geq 1/2$, then $q_2^* = 1$ in addition with $q_1^* \geq 0$ is an interior solution.

[18] Such a solution was $q_1 = \frac{1}{2} + \frac{d-c}{2} - \frac{\gamma\, n}{2}$ and $q_2 = \frac{1}{2} + \frac{d-c}{2} + \frac{\gamma\, n}{2}$.

We notice that $d-c$ must be large enough (at least $-1/2$) that there is a sponsor who is willing to offer the new technology. In case the government wishes to prevent this kind of market failure, it has to raise environmental concern *d* in the population or it has to subsidize the cost of production, *c*.

3. Three types of market structure in an equilibrium

As mentioned before, we do not analyse the dynamics of market entry when network effects may deter it. We only do comparative statics by comparing an equilibrium at the beginning (only firm 1 exists) with an equilibrium where either firm 1 or firm 2 exists, or where both firms compete in the market. We consider two cases of $d-c$. One where the difference is less than $1/2$ and one where it is greater than $1/2$. The case $d-c\in\left[-1/2\,,1/2\right]$ we call weak environmental concern and it implies that we have a corner solution for $q_i\left(q_1^*=0, q_2^*=1\right)$. The formula for the market share θ^* is then as presented in Table 1.

Table 1: Weak environmental concern: $d-c\in\left[-\frac{1}{2},\frac{1}{2}\right]$

$$q_1^*=0\,,\quad q_2^*=1\,,\quad \theta^*=\frac{1}{2}-\frac{d-c}{6\left(1-\gamma\, n\right)}$$

	$d-c=-1/2$	$d-c\in\left(-1/2,0\right)$	$d-c=0$	$d-c\in\left(0,1/2\right)$	$d-c=1/2$
	values of θ^*				
$\gamma\, n=\frac{5}{6}$ [1)]	1	$\frac{\partial\,\theta^*}{\partial\left(d-c\right)}<0$	$\frac{1}{2}$	$\frac{\partial\,\theta^*}{\partial\left(d-c\right)}<0$	0
$\gamma\, n=0$	$\frac{7}{12}$	$\frac{\partial\,\theta^*}{\partial\,\gamma\, n}>0$	$\frac{1}{2}$	$\frac{\partial\,\theta^*}{\partial\,\gamma\, n}<0$	$\frac{5}{12}$

$$p_1=1-\frac{d-c}{3}-\gamma\, n\quad ,\qquad p_2=1+\frac{d-c}{3}+c-\gamma\, n$$

[1)] The SOC of (7), i.e. $2\left(q_2^*-q_1^*\right)-2\,\gamma\, n>0$ implies $\gamma\, n<1$.

If the environmental concern is very weak $\left(d-c=-1/2\right)$, the market share θ^* of firm 1 will be above $1/2$ irrespective of the network effect (column 2 in Tab.1). It can even be 1 if in addition the network effect is strong $(\gamma\, n = 5/6)$. Then firm 1 will remain a monopoly producing energy inefficient $(q_1^* = 0)$ products at low costs $(q_1^*\, c = 0)$, i.e. without investment costs for improved energy efficiency. If the supporting network effect is weak, the market share declines towards $7/12$ and firm 2 can reach a market share up to $5/12$. Its products are costly $(q_2^*\, c = c)$, but environmentally concerned consumers find them attractive and the network is not an obstacle to buy them. We notice that in general a higher network effect favours that firm which had achieved a market share above $1/2$ even without such an effect. Network effects will strengthen the dominance of the successful firm. The more the *d*-effect dominates the *c*-effect, the smaller becomes the market share of firm 1 (column 3).

In case, the *d*-effect balances the *c*-effect (i.e. $d - c = 0$), then the two firms will share the market irrespective of the network effect (column 4). Consumers are indifferent between paying $p_1 = 1 - \gamma\, n$ for the cheaper, energy inefficient product or $p_2 = 1 + c - \gamma\, n$ for the more expensive but energy efficient one.

If the *d*-effect dominates the *c*-effect (i.e. $d - c = 1/2$), then the market share of firm 1 will be below $1/2$, irrespective of the network effect (column 6). The dominating *d*-effect operates in favour of firm 2. It is supported by the network effect because market shares beyond $1/2$ raise the benefit of a network. If the network effect is high $(\gamma\, n = 5/6)$, firm 1 will be driven out of the market because competition forced it to charge a price $p_1^* = 0$ (for firm 2 it is $p_2^* = c + 1/3$). As the partial derivatives indicate, the market share θ^* decreases in $d - c$ (column 5). If environmental concern dominates the cost aspect $(d - c > 0)$, then the market share of firm 1 (it is less than $1/2$) declines with the network effect (column 5), but increases in it (the market share is greater than $1/2$), when environmental concern is very weak (column 3).

Table 2: Prices and profits under weak environmental concern

	$d-c=-\frac{1}{2}$	$d-c=0$	$d-c=\frac{1}{2}$
$\gamma\cdot n=\frac{5}{6}$	$p_1=\frac{1}{3},\ \pi_1=\frac{1}{3}n$ $p_2=c,\ \pi_2=0$	$p_1=\frac{1}{6},\quad \pi_1=\frac{1}{12}n$ $p_2=\frac{1}{6}+c,\ \pi_2=\frac{1}{12}n$	$p_1=0,\quad \pi_1=0$ $p_2=\frac{1}{3}+c,\ \pi_2=\frac{1}{3}n$
	$\frac{\partial p_1}{\partial(d-c)}<0,\quad \frac{\partial \pi_1}{\partial(d-c)}<0,\quad \frac{\partial p_2}{\partial(d-c)}>0,\quad \frac{\partial \pi_2}{\partial(d-c)}>0,$ $\frac{\partial p_i}{\partial(\gamma n)}<0,\quad \frac{\partial \pi_i}{\partial(\gamma n)}<0$		
$\gamma\cdot n=0$	$p_1=\frac{7}{6},\quad \pi_1=0,68n$ $p_2=\frac{5}{6}+c,\ \pi_2=0,34n$	$p_1=1,\quad \pi_1=\frac{1}{2}n$ $p_2=1+c,\ \pi_2=\frac{1}{2}n$	$p_1=\frac{5}{6},\quad \pi_1=0,34n$ $p_2=\frac{7}{6}+c,\ \pi_2=0,68n$

In Table 2 we present the price and profit situation under the different environmental concerns and network impacts discussed in Table 1. As we know from (11) and (12), a well developed network enforces price competition. Prices are highest if there is no network required $(\gamma=0)$. For each $d-c$, profits of both firms increase if the network effect becomes weaker ($\partial \pi_i/\partial(\gamma n)<0$). The worst case for firm 1 is a strong network effect ($\gamma n=5/6$) and environmental concern, dominating the cost aspect $(d-c=1/2)$. The intuition is that firm 1 has problems to attract customers for its less environmentally friendly product and hence does not have a high market share to get support from a strong network effect (its share is zero according to Tab. 1). The worst case for firm 2 is also a strong network effect in addition with a cost aspect that dominates environmental concern $(d-c=-1/2)$. The reason is that the high-cost firm 2 with the environmentally friendly product has problems to get support from the network effect if customers do not care much about the environment (now its market share is zero according to Tab. 1). If environmental concern increases, firm 1 lowers its price to prevent a decline in its market share ($\partial p_1/\partial(d-c)<0$), but firm 2 can increase its price because its product becomes more attractive ($\partial p_2/\partial(d-c)>0$).

Firm 2's first best case is if no network effect is required ($\gamma n=0$) and concern for the environment is high ($d-c=1/2$). In that case, price competition is weak and environmentally concerned consumers ($1-\theta^*=7/12$ or 58%) are ready to pay a high price for those products

$\left(p_2^* = 7/6 + c\right)$. Firm 1 also prefers $\gamma = 0$, but when the cost effect dominates environmental concern ($d - c = -1/2$). It then makes a high profit $\left(\pi_1 = 0.68\, n\right)$ by selling at a relatively high price to 58% of the consumers $\left(\theta^* = 7/12\right)$. In each of these two cases both firms operate in the market.

Table 3: Strong environmental concern: $d - c \in \left[1/2\,,\,5/2\right]$ [19]				
$q_1^* = -\dfrac{1}{4} + \dfrac{d-c}{2}\,,\quad q_2^* = 1$				
	$d - c = 1$	$d - c = 2$	$d - c = 5/2$	$d - c \in \left(1/2, 5/2\right)$
	$q_1^* = 1/4$	$q_1^* = 3/4$	$q_1^* = 1$	$q_1^* \in \left(0,1\right)$
	values of θ^*			
$\gamma\, n = 9/16$	0	- [a)]	$1/2$	$\dfrac{\partial\, \theta^*}{\partial\left(d-c\right)} < 0$
$\gamma\, n = 0$	0.375	0.29	$1/2$	$\dfrac{\partial\, \theta^*}{\partial\left(\gamma\, n\right)} < 0$
[a)] The SOC of (7) implies $\gamma\, n < 1/4$ for this case				
$p_1 = 1/4\left(2\left(d-c\right)-1\right)c - \gamma\, n + 1/48\left(5 - 2\left(d-c\right)\right)\left(11 - 2\left(d-c\right)\right)$ $p_2 = \qquad c - \gamma\, n + 1/48\left(5 - 2\left(d-c\right)\right)\left(13 + 2\left(d-c\right)\right)$				

Table 3 presents the change in the market structure and in environmental quality when environmental concern becomes stronger. As in this case its market share drops below $1/2$, firm 1 raises its environmental quality q_1^* and it even could match with $q_2^* = 1$ when $d - c \geq 5/2$. If environmental concern increases from $d - c = 1/2$ to $d - c = 1$, firm 1 raises its quality q_1^* from 0 to $q_1^* = 1/4$ but will not gain a market share θ^* beyond $1/2$ (column 2 in

[19] $\theta^* = \dfrac{\left(\dfrac{5}{12} - \dfrac{d-c}{6}\right)\left[\dfrac{11}{4} - \dfrac{d-c}{2}\right] - \gamma\, n}{\left[\dfrac{5}{2} - \left(d-c\right) - 2\,\gamma\, n\right]}$

Tab. 3).[20] If $\gamma\, n = 9/16$ and $d - c = 1$, then $p_1^* = c/4 = c\, q_1^*$, i.e. price is equal to average cost. As $p_2^* > c = c\, q_2^*$ in that case, $\theta^* = 0$ is the final market structure. Since the market share does not exceed 0.375, a strong network effect finally leads to market exist of firm 1. We again observe that a strong network effect works in favour of the dominant firm; this time it is firm 2 which has a market share above ½. Similarly, when $d - c = 2$, firm 1 will raise its quality further (from $q_1^* = 1/4$ to $q_1^* = 3/4$), but will not gain a market share θ^* beyond 0.29 (column 3).[21] If $\gamma\, n$ increases, the market share will soon approach zero. We observe that when environmental concern increases, i.e. $d - c$, firm 1 raises its quality q_1^* but nevertheless loses market shares (i.e. $\frac{\partial\, \theta^*}{\partial\left(d-c\right)} < 0$). Finally, the case presented in the 4th column of Table 3 implies that both firms choose $q_1^* = q_2^* = 1$. This would imply that they share the market and charge a price $p_1^* = p_2^* = c - \gamma\, n$ below unit cost. This market structure does not occur because both firms make a loss.[22]

Table 4: Prices and profits under strong environmental concern

	$d-c=1$	$d-c=2$	$d-c=\frac{5}{2}$	$d-c\in\left(\frac{1}{2},\frac{5}{2}\right)$
$\gamma\cdot n=\frac{9}{16}$	$p_1=\frac{c}{4},\quad \pi_1=0$ $p_2=\frac{3}{8}+c,\ \pi_2=0,375n$	*SOC not fullfilled*	$p_i=c-\gamma\cdot n$ $\pi_i<0$ *SOC not fullfilled*	$\frac{\partial\, p_1}{\partial\left(d-c\right)}?$ $\frac{\partial\, p_2}{\partial\left(d-c\right)}<0$ $\frac{\partial\, \pi_i}{\partial\left(d-c\right)}<0$ $\frac{\partial\, p_i}{\partial\left(\gamma\, n\right)}<0$ $\frac{\partial\, \pi_i}{\partial\left(\gamma\, n\right)}<0$
$\gamma\cdot n=0$	$p_1=\frac{9}{16}+\frac{c}{4},\ \pi_1=0,21n$ $p_2=\frac{15}{16}+c,\ \pi_2=0,59n$	$p_1=0,15+\frac{3}{4}c,\ \pi_1=0,04n$ $p_2=0,35+c,\quad \pi_2=0,25n$		

[20] Its market share would be larger than $1/2$ if $\gamma\, n > 3/4$, but the SOC of (7), $2\left(q_2^* - q_1^*\right) - 2\,\gamma\, n > 0$, implies $\gamma\, n < 3/4$.

[21] Its market share would be larger than $1/4$ if $\gamma\, n > 1/4$, but this violates the SOC of (7) which implies $\gamma\, n < 1/4$.

[22] The SOC of (7) and (8), i.e. $2\left(q_2^* - q_1^*\right) - 2\,\gamma\, n > 0$, cannot be satisfied because of the restriction $\gamma \geq 0$.

Table 4 presents the price and profit situation which corresponds to the cases analysed in Table 3. As in Table 2, the profit situation for both firms improves if the network effect becomes less important because in that case price competition is weak and prices are high. Firm 1 responds to an increasing environmental concern by increasing its quality and hence has to raise its price. On the other side, the products become less heterogeneous and price competition will result in lower prices. If the cost effect of producing a higher q_1 dominates the competition effect, then firm 1 might increase its price (see the last column in Tab. 4). As under weak environmental concern firm 1 sticks to $q_1^* = 0$, more environmental concern permits firm 2 to raise its price (see Table 2). The opposite is the case when firm 1 responds by increasing its quality q_1^*.

4. Summary and Conclusion

The existence of network effects plays a crucial role because it can (i) impede the creation of a market, (ii) impede market entrance and (iii) provide market power to the incumbent firm. We considered a duopoly producing horizontally differentiated products which are non-compatible with respect to the network which provides a complementary good. As an example we referred to two automobile producers, one offering cars with an engine powered by gasoline and the other one offering cars with an engine powered by natural gas. The network is petrol stations which provide at present only in a few cases two kinds of fuel. We specified a network effect which is strengthened by the market share of a firm. The equilibrium of the two stage game could be one with either the incumbent firm as the only producer, or one with the innovative firm as the only producer, or one where both firms share the market. Which equilibrium will emerge depends on the cost of production and on environmental awareness of the consumers. The latter aspect has been introduced to give the innovative firm a chance to stay in the market.

In the first stage of our two-stage game the firms decide on the degree of product differentiation in terms of fuel efficiency. In the standard model of this type, firms choose the extreme position, i.e. the end points of the Hotelling 0-1 line. That need not be the case in our model. Now it depends on environmental awareness and the cost of producing energy efficient engines, which type of car will be produced. We have also shown that optimal product differentiation will not be affected by the network effect. This effect exert an impact on price competition, the game at the second stage. The higher the strength of the network effect, the lower will be the equilibrium prices. If a firm has a market share above $1/2$, then its share will increase with the strength of the network effect. For the firm with a market share below $1/2$, its market share will shrink with the strength of the network.

A strong network effect enforces competition and hence profits will be low. The more environmental concern dominates the cost aspect, the lower will be the market share of the firm that produces energy inefficient engines, and the higher will be the share of the entrant producing the new technology. If the network effect is very weak, both firms are in the market. If it is strong, only one firm serves the market – either the conventional producer (very weak environmental concern) or the innovative producer (some environmental concern). The first situation emerges from a parameter constellation for environmental awareness and cost of production which implies as an optimal horizontal product differentiation the extreme 0-1 position. If environmental concern becomes stronger, firm 1 approaches energy efficiency of 1, i.e. the quality choice of firm 2. However, its market share will always drop below 50 percent. This outcome requires a weak network effect. If this effect is strong, then firm 2, having a market share beyond 50 percent, will conquer the market. The effort of the conventional firm to produce an energy efficient engine, equivalent to the natural gas powered engine, ends in fierce price competition and struggle for the network support with losses for both firms.

The objective of our approach has been to sketch a model which captures product differentiation under environmental aspects, the necessity of support by a network, and price competition whereby environmental friendly products are costlier to produce. A topic for future research could be to model the dynamics in an intertemporal setting with control variables (quality, price) and stock variables (market shares). Another topic could be to extend our two stage game by a first stage with competition in compatibility to the network. Such an approach could examine the successfulness of car producers to produce cars with two tanks – one for gasoline and one for natural gas.

References

Arora, S. and S. Gangopadhyay, 1995, Towards a Theoretical Model of Voluntary Overcompliance. *Journal of Economic Behavior and Organization* 28, 289-309.

Bansal, S. and S. Gangopadhyay, 2003, Tax/subsidy Policies in the Presence of Environmentally Aware Consumers. *Journal of Environmental Economics and Management* 45, 333-355.

Chou, C., and O. Shy, 1990, Network Effects without Network Externalities, *International Journal of Industrial Organization*, 8, 259-270.

Chou, C., and O. Shy, 1993, Partial Compatibility and Supporting Services, *Economics Letters*, 41, 193-197.

Church, J., and N. Gandal, 1992a, Integration, Complementary Products and Variety, *Journal of Economics and Management Strategy*, 1, 651-676.

Church, J., and N. Gandal, 1992b, Network Effects, Software Provision, and Standardization, *Journal of Industrial Economics*, 40, 85-104.

Church, J., and N. Gandal, 1993, Complementary Network Externalities and Technological Adoption, *International Journal of Industrial Organization*, 11, 239-260.

Church, J., and N. Gandal, 1996, Strategic Entry Deterrence: Complementary Products as Installed Base, *European Journal of Political Economy*, 12, 331-354.

Conrad, K., 2002, Price Competition and Product Differentiation when Consumers Care for the Environment, Discussion Paper, Mannheim University, No. 609-02.

Crampes, C. and A. Hollander, 1995, Duopoly and Quality Standards. *European Economic Review* 39, 71-82.

Cremer, H. and J.F. Thisse, 1999, On the Taxation of Polluting Products in a Differentiated Industry. *European Economic Review* 43, 575-594.

Economides, N., 1996, The Economics of Networks, *International Journal of Industrial Organization*, 14, 673-699.

Farrell J. and G. Saloner, 1985, Standardization, Compatibility and Innovation, *Rand Journal of Economics*, 16, 70-83.

Farrell J. and G. Saloner, 1986, Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation, *American Economic Review*, 76, 840-955.

Gabszewicz, J. and J.F. Thisse, 1997, Price Competition, Quality and Income Disparities. *Journal of Economic Theory* 20, 340-359.

Greaker, M., 2003, Eco-Labels, Trade and Protectionism. Paper presented at the EAERE Conference in Bilbao.

Grilo, J., Shy o. and J.F. Thisse, 2001, Price Competition when Consumer Behaviour is Characterized by Conformity or Varity, *Journal of Public Economics*, 80, 385-408.

Katz, M.L. and C. Shapiro, 1985, Network Externalities, Competition, and Compatibility, *American Economic Review*, 73, (3), 424-440.

Katz, M.L. and C. Shapiro, 1986, Technology Adoption in the Presence of Network Externalities, *Journal of Political Economy*, 94, 822-841.

Katz, M.L. and C. Shapiro, 1992, Product Introduction with Network Externalities, *Journal of Industrial Economics*, 40, 55-83.

Katz, M.L. and C. Shapiro, 1994, Systems Competition and Network Effects, *Journal of Economic Perspectives*, 8, 93-115.

Lombardini-Riipinen, C., 2003, Endogenous Emission Standards in a Duopoly that is Vertically Differentiated in Environmental Quality. Paper presented at the EAERE Conference in Bilbao.

Matutes, C. and P. Régibeau, 1996, A Selective Review of the Economics of Standardization, Entry Deterrence, Technological Progress and International Competition, *European Journal of Political Economy*, 12, 183-209.

Moraga-González, J.L. and N. Padrón-Fumero, 2002, Environmental Policy in a Green Market. *Environmental and Resource Economics* 22, 419-447.

Motta, M. and J.F. Thisse, 1999, Minimum Quality Standards as an Environmental Policy: Domestic and International Effects. In E. Petrakis, E. Sartzetakis and A. Xepapadeas, eds. *Environmental Regulation and Market Power*, Edward Elgar.

Pfähler, W. and H. Wiese, 1998, *Unternehmensstrategien im Wettbewerb* – eine spieltheoretische Analyse, Springer Verlag, Heidelberg.

Ronnen, U., 1991, Minimum Quality Standards, Fixed Costs, and Competition. *Rand Journal of Economics* 22, 490-504.

Sartzetakis, S. and P. Tsigaris, 2000, Environmental Externalities in the Presence of Network Externalities: The Automobile Market, Discussion Paper, University College of the Cariboo.

Shaked, A. and J. Sutton, 1982, Relaxing price competition through product differentiation. *The Review of Economic Studies* 49, 3-13.

Shy, O., 2001, The Economics of Network Industries, Cambridge 2001.

Wiese, H., 1997, Compatibility, business strategy and market structure – a selective survey, in Holler, M. and Niskanen, E. (eds.), *Frontiers of Standardization*, Vol. 1 of EURAS Yearbook of Standardization, ACCEDO – Publishing Company, Munich, 283-308.