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THE EFFECTS OF TECHNOLOGICAL CHANGE ON THE QUALITY AND VARIETY OF INFORMATION PRODUCTS†

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Anecdotal evidence suggests that producers of information products (TV programs, movies, computer software) may respond to potentially cost-saving technological change by increasing, rather than reducing, their total production investments in the 'first copy' of each product, possibly at the expense of product variety. Comparative statics show that under reasonable assumptions about consumer demand and production technology, competitive firms in a monopolistically competitive industry are in fact induced to increase first-copy investments as a result of either what we define as 'quality-enhancing' or 'cost-reducing' types of technological advance, whereas product variety either falls or stays the same. Results suggest that contrary to often held expectations, potentially cost-saving technological advances in information industries may result in greater market concentration.

Keywords: Information products; Product variety; Product quality; Technological change

JEL Classifications: D24; O33; L82; L86

1 INTRODUCTION AND BACKGROUND

In their classic treatise on the economics of the performing arts, Baumol and Bowen (1968) established that a lack of opportunities for increased productivity in presentation of theatre, symphony concerts, and the like implied that the arts were destined to become more and more costly relative to other goods and services. This would lead to a decline in their availability, unless there were comparable increases in public or foundation subsidy. It is evident, however, that the production of some information goods, such as movies, television programs, and computer software, have been subject to major technological advance. As computer technology has developed over the past two or three decades, special effects have become a key part of Hollywood's movie and television output since software for personal computers came on the scene, technological advances in games and other applications have obviously been dramatic.

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How does technological change in the creation of such information goods affect the quality and variety of products that are made available? Several authors have addressed tradeoffs between product quality and variety in differentiated product industries (Shaked and Sutton, 1987; Sutton, 1991, 2001; Berry and Waldfogel, 2003). The effects of technological advance on these tradeoffs, however, does not appear to have been considered in the economic literature.

How production technology affects such tradeoffs has evident implications for market concentration in information industries. If technological advance tends to favor variety over quality, the result may be fragmentation of market shares. Conversely, incentives to increase product quality relative to variety suggest a rise in industry concentration.

We address these issues using simple theoretical models. We do not attempt to develop general results for the effects of technological change on product quality, variety, or industry concentration. Rather, our purpose is to explain what seems to be a prevalent tendency for the result of technological change in information production to be a triumph of quality (or at least production budgets) over variety – even in cases where the technology is ostensibly cost-reducing. For example, major cost-reducing advances in movie animation made possible by computer generated imagery (CGI) technology since the mid-1990s have, paradoxically, been associated with relatively rapid increases in the production costs of animated films compared with other features films. Although a given film is said to cost $\sim$ 45% less to make using the CGI technology (Eller, 2002), CGI movies released in recent years have an average cost about twice as much as 2D movies.[1]

Often, in fact, observers seem to greet news of production cost-reducing advances in information industries with relief that smaller independent operators – such as desktop publishers, or independent filmmakers with PC animation programs, or cheap digital cameras and editing equipment – will finally have the means to challenge industry domination by well capitalized, established firms. For example, a *Scientific American* article in 2000 declared an independent film production revolution in the making, remarking that 'It is now possible for all of us to try to become desktop Scorceses' (Broderick, 2000, p. 68).

There seems little evidence, though, that such fragmentation actually occurs. The motion picture industry in general, as well as computer games and other applications software, is an apparent example. From 1975 to 2005, average production costs of MPAA-member-produced theatrical features rose $\sim$20-fold (from \$3.1 to \$60.0 million, but there was only a 38% increase in the number of movies that MPAA companies distributed annually in the USA (from 138 to 190) (MPAA, 2006; Waterman, 2005). In spite of dramatic technological advance occurring over this period, market shares of the established studios have remained stable or have increased.[2] Available data for Korean computer game production show that from 1999 to 2003, average development costs per game rose by 237% in Korean won (Korean Game Development and Promotion Institute, 2002, 2004).[1]

Turning to the relevant economic literature, Lancaster (1975), Spence (1976), and Dixit and Stiglitz (1977) first studied tradeoffs between production setup costs and variety in differentiated product markets, with explicit modeling of the television case by Spence and Owen

[1] For details of these data, see Waterman (2004, 2005). Briefly here, the first major CGI movie, *Toy Story*, was released in 1995. Available data show that from the 1992–94 period to the 1998–2002 period, average animated movie production costs increased 178% compared with 84% for non-animated movies. The average budget of CGI animated movies released in the USA from 1998 to 2002 was approximately twice as high as that of 2D movies: \$89.8 *vs.* \$46.9 million, respectively.

[2] Throughout the 1975–2003 period, MPAA-distributed movies have accounted for 80–90% of the total box office in the USA. Market shares of independents were 7.2% in the 2001–3 period, down from a high of 19.0% in the 1986–90 period.); because the MPAA bases its average production cost data on a subset (of undisclosed size) of all MPAA releases, these trends in the number of releases and average costs are not precisely comparable, see Waterman, 2005, reporting data based on *Variety* and the Nielsen-EDI Summary Database.

(1977). These authors generally assumed, however, that setup or first-copy costs, and thus product quality, are exogenous.

Later authors developed endogenous product quality models in which quality can be varied by raising or lowering first-copy costs. Shaked and Sutton (1987) developed such a model in which individual consumers differ in terms of their valuation of quality. They showed that if marginal costs are constant or increase slowly enough, high-quality firms can undercut low-quality firms as market size increases, resulting in a lower bound on industry concentration. Larger markets do not necessarily result in greater product variety. Sutton (2001) built upon that model and his earlier book (1991) to investigate the effects of R&D intensity on industry concentration. As the basis for an extensive empirical study, his theoretical model shows that industry concentration depends positively on the elasticity of product quality with respect to R&D spending and on the substitutability of products at the consumer level.

It is evident that first-copy investment is a central determinant of product quality in information industries and that the level of investment is an important decision variable. Examples include investments in computer software product development, the production costs of movies or television programs, and the creation of newspaper or magazine content. Berry and Waldfogel (2003) developed an endogenous quality model based on Shaked and Sutton (1987) to empirically demonstrate that the average quality of daily newspapers increases with local market size, but that little market fragmentation occurs. That result contrasts with increasing fragmentation as market size grows in the case of restaurants, a product in which quality primarily depends upon variable costs.

Other frameworks have been used to investigate the tradeoffs between the quality and variety of differentiated products with endogenous setup costs and constant marginal costs of production and distribution. Economides (1989) considered the tradeoffs in a model that represents product space along a straight line. Waterman (1990) used a modified version of Salop's (1979) circular model of monopolistic competition, with specific applications to media products, to show that increases in demand (or for the television case, a conversion from advertiser to direct pay support) may induce producers to increase production investments and thus product quality, without necessarily increasing product variety. Economides (1993) showed similar tradeoffs between product quality and variety in a circular model framework, but without direct application to media products.

Turning to our attempt to explain these phenomena, it is useful to conceive of technological change as one of two types: 'cost-reducing' or 'quality-enhancing'. In live action films, for example, computer technology now permits digitally generated movie extras to routinely take the place of live actors. To the extent that such technology results in essentially equivalent outcomes for the movie viewer – such as, perhaps, computer simulation of large crowd scenes – this technology is cost-reducing. We are all familiar, however, with how computer technology has made possible the increasingly spectacular special effects in Hollywood blockbusters. Basically, these advances can be thought of as quality-enhancing. Of course, technological changes in movies and other media can be both cost-reducing and quality-enhancing. In other information product industries, like computer software, there has clearly been a dramatic march forward in development processes on both fronts. Ever faster and efficient computers have greatly shortened the time it takes to carry out a given programming task, and they also make possible far more useful (or fun) software creations.

We develop below a Salop style circular model of monopolistic competition with free entry. Although such 'address' models have well known limitations (Eaton and Lipsey, 1989), this model allows a useful framework for studying the effects of technological advance on market outcomes and consumer welfare. As noted above, however, we do not attempt to arrive at generalizations about the effects of technological change on product quality, variety, and welfare. Rather, the model is mainly intended to demonstrate that with plausibly defined demand and production conditions, the effect of either cost-reducing or quality-enhancing technological change in information industries can simply be increased production (setup) investments, along with reduced, or at least not necessarily greater, product variety.

After setting out the model and its equilibrium results, welfare comparisons are made, followed by discussion and conclusions.

2 MODEL

In the circular framework, product space is represented by the circumference of the circle, its length normalized to 1. Consumers are uniformly positioned along the circumference, with density also equal to 1. The location of each consumer is indicated by X_i. There are a total of n differentiated products, whose locations are indicated by X_j, $j = 1, \ldots, n$. Each individual is assumed to consume only one product (e.g., a differentiated movie, a TV program or a software program), and each firm produces only one product. Firms are also uniformly distributed along the circumference.

The utility of consumer i from consuming product j is defined to be dependent on two factors: (1) x_{ij}, which is defined as the distance in product space between that consumer's location and X_j and (2) a vertical dimension indicating product quality. Just for color, we can think of movies as the information products in question and assume that they consist only of a series of filmed explosions, the number of which is represented by E_j; product quality depends only on this factor. Specifically, define

$$U_{ij} = (1 - \lambda x_{ij}) E_j^{\beta}. \tag{1}$$

The parameter, λ, $\lambda > 0$, measures how rapidly demand falls off with respect to the product's content, and β is the elasticity of demand w.r.t. production investment, where $0 < \beta < 1$ and $U'_{\beta} > 0$, $U''_{\beta} < 0$.

Essentially, this utility function acts as a movie production function in which explosions are the inputs and audience the output. Such a function could take a variety of different forms. Although there is a very large literature on production functions, little of it seems relevant to information products.[3] As specified, the utility (i.e. audience production) function has appealing characteristics. The first derivative of demand with respect to the number of explosions is positive and the second derivative negative. That is, more explosions always help, but there are diminishing returns to audience interest as more and more of them are used. The multiplicative form of the function means that the marginal effect of increasing production investments is to proportionately shift the demand line with respect to content outward.

Without loss of generality, we drop the subscript i, set $j = 1$ and consider only the competition for consumers within the product space between products 1 and 2.

At the point of indifference for the marginal consumer,

$$(1 - \lambda x_{12}) E_1^{\beta} - P_1 = \left(1 - \frac{\lambda}{n} + \lambda x_{12}\right) E_2^{\beta} - P_2. \tag{2}$$

[3] Some related research involves team sports. An empirical study of English Football by Carmichael *et al.* (2000) reviews this literature, beginning with Scully (1974). These studies generally develop linear empirical models to estimate the marginal contributions of vectors of playing skills, or of individual players, to team win–loss records. A number of empirical studies have attempted to estimate the marginal effects of particular actors, Academy Awards, etc., on movie box-office results, using linear regression models (e.g. Smith and Smith, 1986; Ravid, 1999; DeVany and Walls, 1999). Other authors have investigated the production of computer software by comparing performance of alternative functional relationships between output (as measured, for example, by lines of code) and hours of labor input (Hu, 1997).

Profits for firm 1 are defined as

$$\Pi_1 = 2P_1 x_{12} - C_E E_1, \tag{3}$$

where C_E is a constant cost per explosion, so that total production investment $K_1 = C_E E_1$. We assume that the producer faces no other costs than those of producing the film negative (or first copy) itself.

We further assume that all firms make entry, pricing, and investment decisions simultaneously.[4] Solving (2) for x_{12} and substituting into (3), then differentiating (3) w.r.t. P_1 and E_1, applying symmetry assumptions, and adding the zero profit condition yield three equations in three unknowns, E, P, and n. After dropping subscripts, the results, plus the expression for total investment, K, are as follows:

$$E^* = \frac{P^*}{n^*} = \left[\frac{4\beta^2}{(\lambda(2+\beta)^2}\right]^{1/(1-\beta)} C_E^{-1/(1-\beta)} \tag{4}$$

$$K^* = C_E E^* = \left[\frac{4\beta^2}{\lambda(2+\beta)^2}\right]^{1/(1-\beta)} C_E^{-\beta/(1-\beta)} \tag{5}$$

$$P^* = C_E E^* n^* = \left[\frac{4\beta^2}{\lambda(2+\beta)^2}\right]^{1/(1-\beta)} C_E^{-\beta/(1-\beta)} \frac{(2\lambda + \beta\lambda)}{2\beta} \tag{6}$$

$$n^* = \frac{C_E E^* \beta}{P^*} = \frac{(2\lambda + \beta\lambda)}{2\beta} \tag{7}$$

The effects of cost-reducing and quality-enhancing technologies can be separately considered in these equilibrium conditions. Cost-reducing technology simply works through the parameter C_E. That is, a lower C_E means that an explosion with the same audience appeal is cheaper. Quality-enhancing technology works through β. In this case, the utility function shifts upward as β rises. To understand equilibrium effects of technological change, we are thus interested in the total derivatives, $\mathrm{d}E^*/\mathrm{d}C_E$, $\mathrm{d}K^*/\mathrm{d}C_E$, and $\mathrm{d}n^*/\mathrm{d}C_E$, and comparably for the effects of β on E^*, K^* and n^*.

It is evident from (4) that $\mathrm{d}E^*/\mathrm{d}C_E$ is unambiguously negative. As would be expected, that is, a lower cost of producing explosions induces firms to increase the number of them that are used. Of more interest, however, (5) shows that $\mathrm{d}K^*/\mathrm{d}C_E$, total spending on explosions (which in this case represents total movie production costs), also rises with a fall in the cost of the inputs. As (6) shows, the first-order condition for n^* is independent of C_E; product variety thus remains unchanged in response to a fall in input costs. Finally, differentiation of (6) also shows that P^* rises with a fall in C_E.

Differentiation of (4) and (5) shows that $\mathrm{d}E^*/\mathrm{d}\beta$ and $\mathrm{d}K^*/\mathrm{d}\beta$ are both positive if E^*, the number of explosions, is at least 1.[5] Under this condition, that is, a higher audience responsiveness to product quality induces firms to increase the number of explosions used and

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[4] Alternatively, firms could sequentially make entry, quality, and price decisions in a non-cooperative game format. The large number of players in the monopolistically competitive framework, as well as a lack of theoretical guidance as to the appropriate sequence of firm decisions, leads us to choose a simultaneous solution. Economides (1993) derives results using the circular framework for two alternative game structures: a three-stage game in which entry takes place in the first stage, location in the second, and price/quality choice in the third and four-stage game that separates the quality and price choices into two stages. Results of these alternative game structures differ somewhat, but are qualitatively the same with respect to quality and variety tradeoffs.

[5] The exact condition for $\mathrm{d}E^*/\mathrm{d}\beta$ to be positive is $1/C_E\lambda > 2.25$. This condition may hold if $E^* < 1$ depending on these parameter values, but $E^* > 1$ is a sufficient condition. To see how an increase in β could lead to the production of a lower number of explosions when $E^* < 1$, note that $Q'_\beta = (J - \alpha P)E^\beta \ln e < 0$. In that case, a quality-enhancing technology change actually reduces consumers' marginal valuations and quantity demanded at every price, an intuitively perverse result.

total investments per product. P^* also rises with β if $E^* > 1$. As (7) shows straightforwardly, that product variety, n^*, is decreasing in β. Quality-enhancing technologies thus increase production investments at the expense of variety.

As we would expect, (7) confirms that variety is increasing in λ; as audience responsiveness to content increases – or in effect, as the demand for variety rises – variety increases. Conditions (4) and (5) also show straightforwardly that product quality, along with total investments, is decreasing in λ. From (6), prices also fall unambiguously with an increase in λ.

In summary, cost-reducing technological change unambiguously results in increased production investments in the environment of our monopolistically competitive model. As (4) and (5) imply, this happens because the lower costs induce the use of additional explosions at a faster rate than their prices fall. In this model, variety remains unchanged; prices rise with the resulting increase in product investments, but at exactly the same rate as the rise in investments, neutralizing the effects on entry.

Product investments also rise, under reasonable assumptions, as a result of quality-enhancing technology – in these cases at the expense of product variety. The balance of quality and variety is a tradeoff that depends on the elasticity of demand with respect to product quality *vs.* the elasticity with respect to product variety. Other things being equal, an increased responsiveness to quality via an increase in β shifts the balance toward higher investment in fewer products because broader audience products can take better advantage of economies of scale in increasing those investments. Note finally that an outward shift in the utility function via a fall in λ works to increase the marginal impact of increased investments on each consumer within the relevant product space – also moving the quality *vs.* variety tradeoff in favor of the former.

How do outcomes of the competitive models compare with those of the welfare optimum?

Total welfare is the sum of consumers' surplus over all consumers in the market, less the aggregate cost of producing all n products:

$$W = 2n \int_0^{1/2n} E^{\beta}(1 - \lambda \overline{x})\mathrm{d}x - nC_{\mathrm{E}}E. \tag{8}$$

Maximization w.r.t. E and n yields

$$E_{\mathrm{w}}^* = \left[\frac{4\beta^2}{\lambda C_{\mathrm{E}}(1+\beta)^2}\right]^{1/(1-\beta)} \tag{9}$$

$$n_{\mathrm{w}}^* = \frac{(\lambda + \beta\lambda)}{4\beta}. \tag{10}$$

From (4) and (7), respectively,

$$E_{\Pi}^* < E_{\mathrm{w}}^* \tag{11}$$

$$n_{\Pi}^* = 2n_{\mathrm{w}}^* + \frac{\lambda}{2\beta}, \tag{12}$$

where Π indicates the maximum profit outcome. Comparable to the results of Salop (1979), Waterman (1990), and Economides (1993) and some other models based in the circular framework of monopolistic competition, variety tends to be overproduced. Also, individual firms underinvest in quality. Moreover, it is easily shown that $E_{\Pi}^* n_{\Pi}^* < E_{\mathrm{w}}^* n_{\mathrm{w}}^*$. That is, aggregate industry investment is also below the welfare optimum.

It is well known that welfare results in differentiated product models are subject to the particular form of the demand function, and this model is no exception. Nevertheless, welfare results seem to give us little cause for concern that higher investments in themselves, even at the expense of variety, reduce welfare.[6]

Both the equilibrium and welfare results of the above model can be extended to a multiple input case with qualitatively similar findings.[7]

3 CONCLUSIONS

Under plausible demand and cost conditions, either cost-reducing or quality-enhancing technological change may induce producers of information products to increase first-copy (sunk cost) investments. In a competitive market, product variety may fall as a result of quality-enhancing technology and may, at least, not increase as a result of cost-reducing technology. The implication of these results – that technological advance in information production may result in higher market concentration rather than market fragmentation – parallels the finding of Berry and Waldfogel (2003) that larger market size fails to result in fragmentation in the case of daily newspapers because incumbent firms can undercut rivals by expanding product quality.

The novel feature of the models in the present analysis is simply that inputs (in the presented case, a single input) appear in both the firm's demand and cost functions. That is, inputs are potentially quality-enhancing. Under those conditions, even a straightforward cut in the wholesale price of an input in the production process, for example, induces the firm to increase total outlays on that input. This occurs because the input is not only cheaper to use, but higher use of it is quality-enhancing, in turn increasing demand.

Our basic findings apply to any product having setup costs and constant marginal costs of production in which quality is embodied in setup rather than incremental costs. We have not, however, dealt with a number of other typical characteristics of the primary object of our analysis – information products – which can also affect market structure and welfare outcomes. In information industries such as computer software, for example, powerful network effects can enhance a tendency toward monopoly, and thus high-cost products, at the expense of variety. Copying and piracy of information products are also factors. Other things being equal, piracy and copying tend to reduce production incentives, reducing both quality and variety, although it is reasonable to suppose that these activities disproportionately affect relatively expensive, broad-appeal products.

It is also evident that even apart from the welfare findings, our results are not necessarily robust to alternative specifications of the production (i.e. demand) function. The basic relationship between production inputs and demand in our models, however, is straightforward and plausible and thus suggests insights into whether certain developing technological changes – such as cheaper digital cameras for independent filmmakers – are likely to result in a need to make lower investments, thus inducing higher variety, or vice versa. If cheap digital cameras simply reduce movie production costs, but offer few opportunities to increase production quality, their dominant result is likely to just be lower total production costs. If the dominant effect of such digital equipment is to create new opportunities for producers and directors to improve production values, the result may in fact be of higher quality with no fragmentation and, possibly, increased concentration.

[6] A caveat to this observation is the extent to which higher movie budgets reflect higher rents paid to talent. It is not clear, however, whether a similar phenomenon would accompany a shift toward higher variety for a given level of total production investments.

[7] See Waterman (2004).

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