The Effects of Technological Change on the Quality and Variety of Information Products

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Revised April 27, 2004

I am grateful to Jun-Seok Kang, Weiting Lu, Byungho Park, and Xiaofei Wang; their excellent research assistance has contributed importantly to this paper. An earlier version of this paper was presented at the 2004 International Industrial Organization Conference, Chicago, April 23-24, 2004. I am grateful to participants there, and also to Mike Baye and Thom Gillespie, for comments.

Abstract

Anecdotal evidence suggests that producers of information products (TV programs, movies, computer software) may respond to potentially cost saving technological change by increasing, not reducing, their total production investments in the "first copy" of each product, possibly at the expense of product variety. Models presented in this paper show that under reasonable assumptions about consumer demand and production technology, a monopolist is 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. In a competitive industry, first copy investments also rise for both types of technological change, while variety falls or stays the same. Results suggest that contrary to often held expectations, potentially cost saving technological advances in information industries may result in higher barriers to entry and greater concentration. Descriptive data, primarily covering animated theatrical feature films, are presented in support.

I. Introduction and background

This paper addresses questions about the technology of creating information products. In their classic treatise on the economics of the performing arts, Baumol & 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. That 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, has recently been subject to major technological advance. As computer technology has developed, special effects have become a key part of Hollywood's movie and television output. Computer software, of course, has been made possible by computers themselves, and technological advances in games and other applications have obviously been dramatic.

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 & Sutton, 1987; Sutton, 1991, 2001; Berry & Waldfogel, 2003). How technological advance affects such tradeoffs does not appear to have been addressed. An understanding of these effects has evident implications for market concentration in information industries. In particular, if technological advance favors incentives to increase quality over variety, the result may be greater industry concentration or barriers to entry, possibly through strengthened network effects. Conversely, greater incentives to increase variety would tend to fragment markets.

This paper takes a modest step toward addressing these issues, using some simple theoretical models, with supporting descriptive data. We do not attempt to develop general results for the effects of technological change on product quality, variety or industry concentration. Rather, the main purpose of the paper is to suggest an explanation for what seems to be a relentless tendency for the result of technological change in information production to be a triumph of quality over variety—even in cases where the technology is ostensibly cost-reducing.

A. Some descriptive evidence

To illustrate this observation, we report some curious, perhaps counter-intuitive behavior of animated movie producers in response to recent strides in computer production technology. The animation genre was dramatically, and rather suddenly, affected by advances in digital technology in the mid-1990s. Up to that time, "cell animation" (or "2-D") was the prevailing technology. In this method, an artist draws each frame of the movie separately, and then a camera turns them into full motion by filming 24 (more or less) of these frames per second to create the illusion of smooth movement. With the highly successful 1995 movie, *Toy Story*, the production company, Pixar, pioneered a new technique of computer-generated animation on a commercial level (called computer generated imagery, or CGI) (Levin, 1996). In the opinion of many observers, CGI permits a more engaging range of character movements as well as visual effects. Attracting particular attention in the trade press, however, was that movies could be made far more cheaply with CGI technology (Levin, 1996; Gubernick, 2003). As one press report has recently observed:

> They [CGI movies] are particularly appealing to studios because they're much cheaper and quicker to produce. The rule of thumb, [Sony Pictures executive Penny Finkelman] Cox says, is that it takes 400 artists four years to bring a 2-D movie to theaters. It takes half that number in three years for a computer-generated movie. As a result, a digital movie typically costs about $80 million, compared with $150 million for a traditional animated feature (Eller, 2002, B3, p.1)

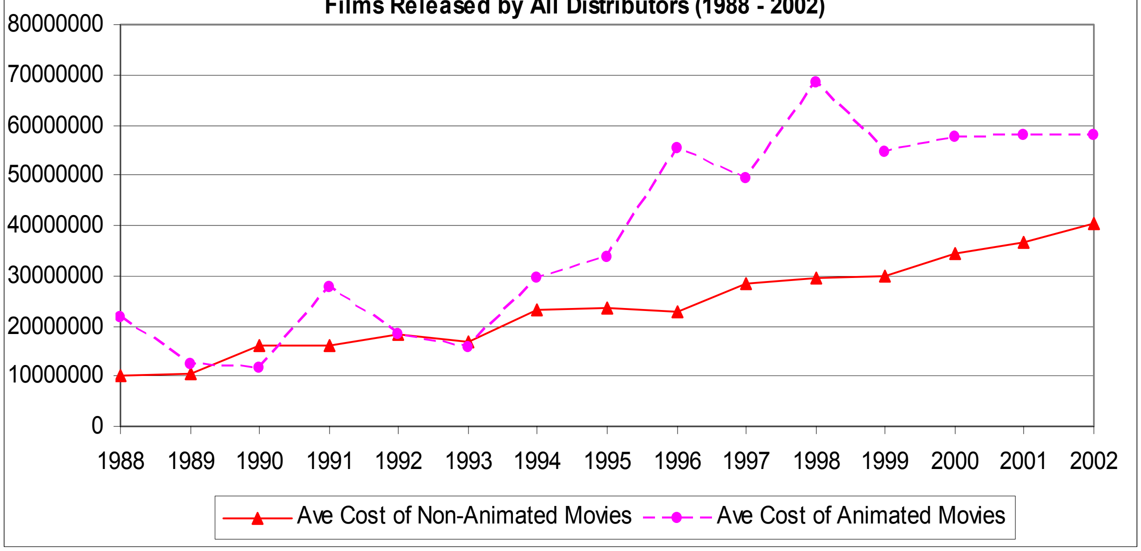
These cost differences led industry observers in the wake of *Toy Story* to predict a revolution in animation. *Toy Stor*y's box-office success has indeed led to a widespread industry shift toward CGI technology for major animated feature films. The next major CGI movie to appear was released in 1998 (*A Bug's Life*, distributed by Disney), and at least thirteen others followed up until the end of 2002.[1] (Among major productions, these

[1] Data reported in this and the following two paragraphs cover only animated movies for which production cost data were available. These movies accounted for 96% of the box-office receipts earned by all animated movies over the 1988-2002 period. See Appendix A for more detailed data in support of the narrative in these three paragraphs.

twelve movies accounted for a relatively small proportion, about 27% of the 48 animated movies that were released in the U.S. from 1998-2002 (not including re-issues). CGI movies accounted for 40%, however, of Hollywood's production investments in movies released during this period. The CGI movies have been successful as a whole, earning 51% of all box-office revenues earned by these 48 movies. We lack systematic data on movie production costs and revenues after 2002, but it is evident that a major studio shift to CGI technology continues, as demonstrated by press reports that *Home on the Range* (2004) would be Disney's last traditional 2-D animated feature release.[2]

To be expected, the variety of animated movies, as measured by the overall number of major animated movies released, has substantially increased, rising from 2.1% of major releases over the 1988-1997 period to 5.9% of movies released from 1998-2002. Trends in animated film production budgets, however, were the opposite of what many people seemed to expect. As Figure 1 shows, the average cost of animated movies released in the United States generally tracked those of all movies until the mid-1990s, but since then, has risen much faster than production costs of non-animated movies.

Figure 1
Trends in Production Costs of Animated and Non-Animated U.S. Theatrical Feature Films Released by All Distributors (1988 - 2002)



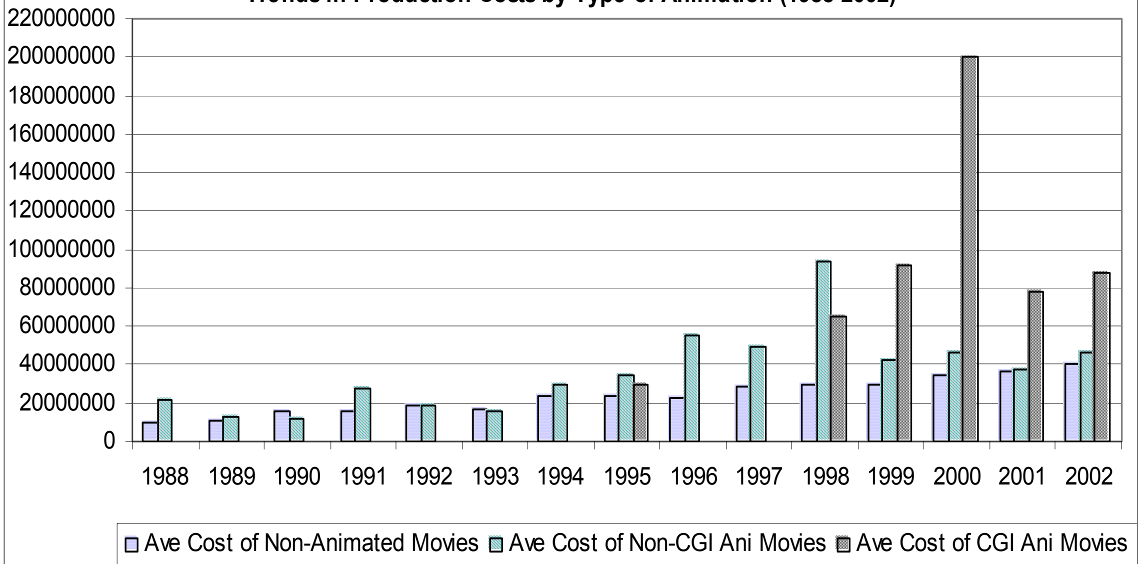
Source: EDI, see Appendix A

The cost divergence began before any major CGI productions reached the market in 1998, and a handful of the higher budget post-1995 animated productions, most of

[2] Whipp, G., Drawing to a close: "Home on the Range" may be Disney's last stand at hand animation, Los Angeles Daily News, April 2004, p. 1.

them produced by Disney, have been 2-D films, including *The Emperors New Groove* (2000, $100 million cost), *Titan A.E.* (2000, $75 million), and *Treasure Planet* (2002, $140 million). As shown in Figure 2, however, CGI productions have tended to have the highest budgets, including *Monsters, Inc* (2001, $115 million), *Dinosaur* (2000, $200 million), and later, *Finding Nemo* (2003, $80 million). The average cost of CGI movies released from 1998 to 2002 was $89.7 million compared to $46.9 million for 2-D films.[3] Movie producers switching to the "cheaper" CGI technology have thus chosen to spend more--not less--on their productions.

Figure 2
Trends in Production Costs by Type of Animation (1988-2002)



Source: EDI, see Appendix A

While these facts abstract from a more complex story about competitive changes in the animation industry that we return to below, they hardly indicate that movie producers have realized the opportunity to cut down on movie production budgets by switching to CGI technology.

Apart from the movie animation example, observers often seem to greet news of production cost-reducing advances in information industries with relief that smaller independent operators will finally have the means to challenge industry domination by highly capitalized, established firms. Desktop publishers can create professional quality

[3] Four of the CGI movies combined animation with live action. Their average cost was $96 million, which would make the comparison slightly less extreme. See Appendix A.

magazines or books from home, or skilled individuals with handheld mini-cams can break the control of television news production by a few large networks or stations. There has been a recent wave of optimism for independent movie producers. Citing a decline in the cost of shooting and editing with 35 mm film of $4865 per hour to $20 per hour with a mini-DV camera and video editing equipment, a *Scientific American* article 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 fragmentation actually happens, and entertainment production costs, at least, seem to climb relentlessly. From 1975 to 2002, for example, average production costs of MPAA-member produced theatrical features rose almost 19-fold (from $3.1 to $58.8 million), but there was only a 59% increase in the number of movies that MPAA companies distributed annually in the U.S. (from 138 to 220) (MPAA, 2002; Paul Kagan Associates).[4] It is evident that a large increase in consumer demand due to the development of pay TV and video media has fueled the increase in aggregate investments. There also seems little doubt that higher rents paid to major talent have been largely responsible for film budget increases.[5] Movie production technology, however, has evidently advanced throughout this period as well, from the mechanical constructions and model photography of *Jaws* (1975) and *Star Wars* (1977), to spectacular computer effects of *Harry Potter and the Sorcerers Stone* (2001) and the *Lord of the Rings* trilogy (2001, 2002, 2003).

Another information industry in which rising costs have accompanied dramatic technological advance is computer games. Investments per game are reported to be rising dramatically.[6] 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, 2003).[7]

[4] Throughout this period, MPAA-distributed movies have accounted for 80 to 90% of the total box-office in the United States. Because the MPAA bases its average production costs on a subset (of undisclosed size) of all MPAA releases, these trends are not strictly comparable.

[5] Among many trade articles on the subject, see Cox (1995) and Welkos, R.(1999).

[6] See, for example, summaries of Screen Digest (2003, March), and Spectrum Strategy Consultants (2002)

[7] These data are derived from statistics reported for 1157 games for which development grants were requested from the Korean Game Development and Promotion Institute.

B. Previous research

Tradeoffs between production setup costs and variety in differentiated product markets have long been recognized and studied in the economic literature (Lancaster, 1975; Spence, 1976, Dixit and Stiglitz, 1977). These authors have shown how product variety and consumer welfare vary with set up costs, demand parameters, and a variety of other market conditions. Spence and Owen (1977) studied the television industries explicitly within such a framework. These authors have generally assumed, however, that set up or first copy costs, and thus product quality, are exogenous.

Later authors developed endogenous quality models in which product quality can be varied by raising or lowering set up, or first copy costs. Shaked and Sutton (1987) develop such a model in which individual consumers differ in terms of their valuation of quality. They show 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, that is, do not necessarily result in greater product variety. Sutton (2001) builds upon that model and Sutton (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. Rosse (1967) recognized these relationships in his empirical study of the newspaper industry. In a recent paper, Berry and Waldfogel (2003) develop an endogenous quality model based on Shaked & Sutton (1987) to empirically demonstrate that the average quality of daily newspapers increases with local market size, but that market fragmentation does not occur. That result contrasts with increasing fragmentation as market size grows that they find 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) considers the tradeoffs in a model that represents product space along a straight line. Waterman (1990) uses 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. Waterman (1992) develops a "program choice" model representing a producer of media products with monopoly power and uses it to explain the tendency for motion picture distributors to increase budgets rather than to produce larger numbers of movies.[8] Economides (1993) shows similar tradeoffs between product quality and variety in a circular model framework, but without direct application to media products.

Finally, to represent the effects of technological change requires the specification of a production function for information goods. While there is a large literature on production functions, little of it seems to involve production processes characteristic of information products. Some related research involves team sports. A recent empirical study of English Football by Carmichael, Thomas, & Ward (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 boxoffice results, using linear regression models (eg, Smith and Smith, 1986, Ravid,1999; DeVany & Walls, 1999). Other authors have investigated the production of computer software by estimating how well alternative functional relationships between output (as measured, for example, by lines of code) and hours of labor input (Hu, 1997). Overall, the economic literature on production appears to offer relatively little guidance for appropriate functional forms that represent the effects of technological change on the production process for information goods.

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[8] See Owen and Wildman (1992) for a survey of program choice models.

II. Assumptions and Models

Turning to the present analysis, 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. For the great majority of movies, these and other special effects make up a relatively small proportion of their total product budgets, so that the impact of advances in digital technology on total costs are potentially much less than in animation. Substantial savings in the cost to shoot a given scene are nevertheless possible. To the extent that such technology results in essentially equivalent outcomes for the movie viewer, this technology is cost reducing. On the other hand, we are all familiar with how computer technology has made possible the increasingly spectacular special effects in Hollywood blockbusters that clearly enhance enjoyment of these movies. Basically, these technologies 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.

To better understand the effects of technological advance in information industries, four theoretical models representing alternative market structures and assumptions about production inputs are presented. These frameworks do not permit generalizations about the effects of technological change on product quality and variety. Rather, they are 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 investments, along with reduced, or at least not necessarily greater, product variety.

In the first model to follow, we consider the case of a monopolist producing a single information product that has only one variable input. In that model, quality, but not variety, can vary. In a second model, we consider a two variable input case for the monopoly case. In the third and fourth models, we consider a monopolistically competitive industry in which firms employ a single input, and two inputs, respectively, in a Salop-style circular model. In those models, both quality and variety can change. Selected welfare results are also reported.

A. Model I: Single Input Monopoly

Just for color, say that movies consist only of a series of filmed explosions, and that the producer faces no other costs than those of producing the film negative (or first copy) itself. In this case, the only decision variable of the producer is how many explosions to include in the movie.

Define

$$(1)\ \Pi = P(J\text{-}\alpha P)E^{\beta} - C_E E$$

where: demand, $Q = (J\text{-}\alpha P)E^{\beta}$; P = price; J and α are demand parameters, where $J, \alpha > 0$; E = number of explosions; C_E = constant cost per explosion; β = the elasticity of audience demand w.r.t. to the number of explosions in the movie.. We assume that $0 < \beta < 1$, and that the first derivative of demand w.r.t. E 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. Total production investment is $K = C_E E$. The multiplicative form of the demand function means that the marginal effect of increasing production investments is to proportionately shift the demand line with respect to price outward.

The firm maximizes profit w.r.t. P and E, yielding:

(1) $P^* = J/2\alpha$

(2) $E^* = (J^2\beta/4\alpha)^{1/(1-\beta)} C_E^{-1/(1-\beta)}$

(3) $K^* = C_E E^* = (J^2\beta/4\alpha)^{1/(1-\beta)} C_E^{-\beta/(1-\beta)}$

The effects of cost reducing and quality enhancing technologies can be separately considered in this model. 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 can be interpreted to work through the parameter β. That is, the audience demand function w.r.t. E shifts upward if β is higher. Alternatively, quality-enhancing technology could operate through an outward shift of the demand function with respect to price: that is, an increase in J, a decrease in α , or some combination. By the latter mechanisms, the effects of increasing the number of explosions on audience size are magnified accordingly

To understand equilibrium effects of technological change, we are interested in dE^*/dC_E and dK^*/dC_E, $dE^*/d\beta$ and $dK^*/d\beta$, and comparably for the J and α parameters.

It is easily shown from (3) and (4) that $dE^*/d\beta > 0$, $dE^*/dJ > 0$, $dE^*/d\alpha < 0$, and thus $dK^*/d\beta > 0$, $dK^*/dJ > 0$, and $dK^*/d\alpha < 0$. As we would expect; quality enhancing technology by any of these mechanisms increases incentives to invest in movie explosions. It is also evident from (3) and (4) that both dE^*/dC_E and dK^*/dC_E are unambiguously negative. A lower cost of explosions, that is, increases the number of them used as we expect; also, the lower cost results is greater total spending on explosions (which in this case represents total movie production costs) because the total number of explosions used rises faster than costs per explosion fall.

A numerical illustration

A simple example can compare the potential effects of quality-enhancing and cost-reducing inputs in the single input monopoly case. Using (1) above, let $J = 200$ and $\alpha = 1$ for an initial case. From equation (2), $P = 100$ and $P(J\text{-}\alpha P) = \$10,000$. Also let β, the elasticity of demand with respect to the number of explosions, equal .5.

The first row of Figure 3 shows that for the initial case, the marginal value of the first explosion in a given movie (ie, $P(J- \alpha P)E^{\beta}$, where $E = 1$) is $10,000. As the last three columns show, there are diminishing returns to audience demand from including additional explosions (as E rises to 2, 3, and 4).

Figure 3
Illustration of the effects of technological change:
The single input monopoly case

Number of explosions	1st	2nd	3rd	4th
Marginal value, initial case	$10,000	$4,142	$3,178	$2,680
Marginal value, doubled impact	$20,000	$8,284	$6,356	$5,360

If we assume for the initial case that each explosion costs $6,000, the profit maximizing result is that only one explosion is used, since demand only rises by $4,142 for the second.

Now, however, consider a quality-enhancing technological change, such as an improvement in the realism of explosions from computer enhancement. If we say that demand simply doubles for each number of explosions used (in terms of (1), this represents a doubling of $J^2/4\alpha$. As indicated in Figure 3, the marginal value of explosions jumps to those on the bottom row of the table. In this case, three explosions will be used, at a total cost of $18,000. The number of explosions used in the movie thus triples, as does the amount of money spent on them.

Consider finally a cost-reducing technology for explosions. That is, say the same explosion becomes only half as expensive to conduct, the cost dropping from $6000 to $3000 each. The producer's response in this case is also to increase the number of explosions from one to three. Total movie production expenditures increase in this case as well, though only from $6000 to $9000.

In both the quality enhancing and cost reducing cases, the response to improved movie production technology is to expand the scope of production with more inputs, and at a greater total investment.

B. Model II: Two Input Monopoly

Model I can be made more realistic by increasing the number of inputs used in the movie production process. Here, we think of movies as consisting of two inputs, explosions (*E*), and stars (*S*).

Define:

(5) $\Pi = P(J\text{-}\alpha P)E^{\beta} S^{\gamma} - C_E E - C_S S,$

where S = number of stars, and C_S is the constant cost of stars. The constraints on β assumed in model I again apply, and comparably, $0 < \gamma < 1$, and $S'_\gamma > 0$, and $S''_\gamma < 0$. That is, the elasticity of demand w.r.t. the number of stars is also below 1 and increases with more stars at a decreasing rate.

In this model, then, demand is defined in the form of a standard Cobb-Douglas production function. In effect, the number of consumers who watch the movie is "produced" by the combination of inputs. Like a standard production function, we also assume that $\beta + \gamma < 1$. That is, there are decreasing returns to scale; a doubling of both the number of stars and the number of explosions will result in less than a doubling of demand, surely a reasonable assumption.

Maximizing w.r.t to *P, S,* and *E*, and taking the simple case of $\gamma = \beta$ for tractability, yields:

(6) $P^* = J/2\alpha$

(7) $E^* = (J^2\beta/4\alpha)^{1/(1-2\beta)} C_E^{(\beta-1)/(1-2\beta)} C_S^{-\beta/(1-2\beta)}$

(8) $S^* = (J^2\beta/4\alpha)^{1/(1-2\beta)} C_E^{(\beta-1)/(1-2\beta)} C_S^{-\beta/(1-2\beta)}$

(9) $K^* = C_E E^* + C_S S^*$

Second order conditions require β < .5 for a maximum, which is consistent with the assumption of $\beta + \gamma < 0$, given $\beta = \gamma$.

Again, as we would expect, total differentiation shows that $dE^*/dJ > 0$, $dE^*/d\alpha < 0$, and $dE^*/d\beta > 0$, and as long as α, C_E and C_S are not too large relative to J, $dE^*/d\beta$ is also positive.[9] Following from the $\beta = \gamma$ assumption, the comparable derivatives of S^* w.r.t. to these parameters are identical. It follows that K^* is also increasing (decreasing) in these same parameters. That is, an outward shift in demand w.r.t. price or a higher elasticity of demand w.r.t. either explosions or stars increases total production investments.

We also find that dE^*/dC_E and dS^*/dC_S are unambiguously negative, as we would again expect. Furthermore, however, (9) reveals that dK^*/dC_E, and dK^*/dC_S are also unambiguously negative.

These results parallel those of model I, but the positive effect of one input's cost reduction on total production investment has a more interesting interpretation, because of a positive demand interaction effect between S and E. In particular, a fall in C_E results in more explosions being used, but even though that in itself induces the producer to substitute away from stars into explosions, the net effect is also to increase the number of stars used, and thus total spending on stars. That occurs because with more explosions, the Cobb-Douglas form of the demand function means that there is a higher marginal effect on demand for each star that is used. In this respect, the multiplicative Cobb-Douglas form has intuitive appeal. Unless production values are sufficiently high in other respects, it may not be cost-effective to hire a popular star.

In summary, the result of the two input model is also that a lowering of production factor costs, as well as a quality-enhancing technological change, may induce producers to increase, rather than to reduce, total production investments.

[9] The exact condition is $J^4/(\alpha^2 C_E C_S) > 64$

C. Model III: Monopolistic Competition, Single Input

Of course, Models I and II ignore the competitive environment and do not treat changes in variety explicitly. In this third model, I allow both product variety and quality to vary, using a circular "address" model of monopolistic competition (Salop, 1979).

In that 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, 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, E_j, which comparably to the earlier models, I again let it be an indicator of product quality, represented simply by the number of explosions in the movie. Specifically, I define:

$$(10)\quad U_{ij} = (1 - \lambda x_{ij})E_j^{\beta}$$

where $0 < \beta < 1$ and $U'_{\beta} > 0$, $U''_{\beta} < 0$ Here again, β is the elasticity of demand w.r.t. production investment.

Without loss of generality, 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:

$$(11)\quad (1 - \lambda x_{12})E_1^{\beta} - P_1 = (1 - \lambda/n + \lambda x_{12})E_2^{\beta} - P_2.$$

Profits for firm 1 are then:

$$(12)\quad \Pi = 2P_1 x_{12} - C_E E_1$$

We assume that all firms make entry, pricing and investment decisions simultaneously.[10] Solving (11) for x_{12} and substituting into (12), then differentiating (12) w.r.t. P_1 and E_1, applying symmetry assumptions and adding the zero profit condition, yields three equations in three unknowns, *E, P,* and *n:*

(13) $n^* = \lambda C_E E^* \beta / P^* = (2\lambda + \beta\lambda)/2\beta$

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

(15) $K^* = C_E E^* = [4\beta^2/(\lambda(2+\beta)^2]^{1/(1-\beta)}\ C_E^{\ -\beta/(1-\beta)}$

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

Total differentiation reveals that variety, n^*, is decreasing in β, and is increasing in λ. The investment measures, E^* and K^*, are unambiguously decreasing in λ, and they are increasing in β as long as C_E and λ are not too large.[11]

The interpretation of these results is that increased consumer responsiveness to a given production investment shifts the balance toward higher investments in individual products relative to product variety. Thus, quality-enhancing technological improvements lead to greater investments in a smaller variety of products. Differentiation also shows that P^* rises with β, indicating that higher prices can be charged for higher quality products.

It is evident from examination of (13)-(15) that a decline in C_E leads, as would be expected, to an increase in E^*, but also to an increase in total investments, K^*. As in Models I and II, cost-saving technological change thus leads to an increase in the total number of explosions and in the total amount spent on them. In this case, however, n^*, product variety, remains unchanged. Prices rise with the increase in investments as

[10] 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. The four-stage game separates out the quality and price choices into 2 stages. Results differ somewhat, but are qualitatively the same with respect to quality and variety tradeoffs.

[11] The exact condition for $dE^*/d\beta$ to be positive is $1/C_E\lambda > 2.25$

before, but at exactly the same rate as the rise in investments, neutralizing the effects on entry.

D. Model IV: Monopolistic competition, two inputs

The model setup is comparable to that of Model III, except for two potentially quality-enhancing inputs, explosions and stars, instead of just explosions.

Define:

$$(17)\ U_{ij} = (1- \lambda x_{ij})E_i^{\beta} S_j^{\gamma}$$

where $0 < \beta < 1$, $U'_{\beta} > 0$, $U''_{\beta} < 0$, and comparably for γ. The point of indifference of the marginal consumer between products 1 and 2 is defined comparably to (11) above, and profits are defined to be:

$$(18)\quad \Pi = 2P_1 \bar{x} - C_E E_1 - C_S S_1 = 0$$

The representative firm maximizes w.r.t. P_1, E_1, and S_1. Applying symmetry and adding the zero profit condition yields four equations in four unknowns, P, E, S, and n. Again we take the simple case of $\beta = \gamma$, which implies $S = (C_E / C_S)\ E$. Second order conditions require $\beta < .5$. Resulting are:

$$(19)\ n^{*} = (\lambda+\lambda\beta)/2\beta$$

$$(20)\ E^{*} = [2\beta^2/ \lambda\ (\beta+1)^2]^{1/(1-2\beta)}\ C_E^{(\beta-1)/(1-2\beta)}\ C_S^{-\beta/(1-2\beta)}$$

$$(21)\ K^{*} = C_E E^{*} = [2\beta^2/ \lambda\ (\beta+1)^2]^{1/(1-2\beta)}\ C_E^{-\beta/(1-2\beta)}\ C_S^{-\beta/(1-2\beta)}$$

Symmetric equations to (20) and (21) result for S^{*} and $C_S S^{*}$.

Given these equilibrium conditions, product variety, n^{*}, is increasing in λ and declining in β. Differentiation of (20) reveals that E^{*}, and thus $C_E E^{*}$ are rising in β as long as λ, C_E and C_S are not too large.[12] Differentiation also reveals that total investment ($C_E E^* + C_S S^*$) rises under the same conditions with quality-enhancing technological change.

Examination of (20) and (21) further reveals that both E^*, $C_E E^*$, and K^* rise with a fall in C_E (and comparably for C_S). Similarly to the 2-input monopoly model, competitive producers respond to cost-reducing technological change by increasing investments, an effect that is enhanced by the positive demand interaction effects between stars and explosions.

In summary, the competitive model shows that first copy investments rise for both types of technological change; in the case of quality-enhancing technology, product variety declines, while in the cost-reducing case, rising first copy investments are accompanied by no change in variety. In the latter case, product variety declines, while in the cost-reducing case, variety remains constant as investments, and thus product quality, rise.

E. Welfare analysis

How do outcomes of the competitive models compare with those of the welfare optimum? Since results are qualitatively the same for the single input and two input models, only the two input model results are reported.

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

$$(22)\ W = 2n\int_0^{1/2n} E^{\beta} S^{\gamma}(1-\lambda \bar{x})\, dx - n\, C_E E - n\, C_S S$$

Maximization w.r.t. n, E, and S, again assuming $\beta = \gamma$, and $\beta < .5$, yields:

$$(23)\ n_w^* = (\lambda+2\beta\lambda)/8\beta$$

$$(24)\ E_w^* = [8\beta^2/\lambda(1+2\beta)^2]^{1/(1-2\beta)}\ C_E^{(\beta-1)/(1-2\beta)}\ C_S^{-\beta/(1-2\beta)}$$

[12] The exact condition for $dE^*/d\beta$ to be positive is $1/\lambda^2 C_E C_S > 20.25$.

and comparably for S^*.

From (19) and (20), respectively:

(25) $n_\Pi^* = 2n_w^* + \lambda/4\beta$

(26) $E_\Pi^* < E_w^*$

where Π indicates the maximum profit outcome. Comparable to the results of Salop (1979), Waterman (1990), and Economides (1993) for other models based in the circular framework of monopolistic competition, variety tends to be overproduced, and individual firms under invest. Moreover, it is easily shown that $E_\Pi^* n_\Pi^* < E_w^* n_w^*$. 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.[13]

III. Discussion and conclusions

The theoretical models introduced in this paper show that 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.

A basic model feature driving these results is that all inputs appear in both the firm's demand and cost functions. That is, all inputs are potentially quality enhancing. Under those conditions, even a straightforward cut in the wholesale price of any one

[13] 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.

input in the production process, for example, induces the firm to increase total outlays on that input, because it is not only cheaper to use, but higher use is quality enhancing, in turn increasing demand.

Recognition of this assumption permits insight into whether certain developing technological changes, such as the cheaper digital cameras cited by Broderick (2000) that might turn us all into "desktop Scorceses," are likely to result in lower investments and higher variety, or *vice versa*. If cheap digital cameras simply reduce movie production costs, but offer few opportunities to increase production quality by using more of them or using them in new ways, their dominant result is likely to just be lower total production costs.

An important feature of production technology's impact not directly captured by the models of this paper is its differential effect on high vs. low end products. Below-the-line production costs, which include cameras and other hardware, tend to account for substantially larger fractions of low end movie budgets, and as Broderick's commentary indicates, reductions in these costs can have a dramatic impact on the feasibility of making lowest end, independently produced films.[14] It is likely, as Broderick implies is already happening, that the availability of low cost digital cameras and other digital equipment is stimulating a fringe industry of relatively marginal independent producers. We are currently investigating whether CGI technology has had this effect on the prevalence of lower budget, independently produced animated features.

The "more-more" finding in the two input models—that is, the positive demand interaction effect, such that a fall in the cost of one input induces the producer to increase the use of both inputs--contrasts with other explanations for why high quality inputs tend to be combined with other high quality inputs in multi-input product processes. Reliability theory in economic and operations research predicts generally that this phenomenon occurs because the negative consequence of having a "weakest link" increases on the margin as the quality of other inputs rises. (See, for example, Kremer, 1993). In a sociological analysis of labor inputs into motion picture productions, Faulkner

[14] A hypothetical budget comparison between a $79.2 million and a $4.8 million version of the same movie indicated total below-the-line expenses to be 40.0% of the high budget, vs. 70.2% of the low budget movie, including 2.3% for "camera" and " production raw stock & lab" in the former case, vs. 5.3% in the latter (Linson, 1997). Broderick (2000) describes lower budget examples in which camera and related costs are much larger percentages of total production budgets.

(1987) argues that cumulative career attainments are governed by the propensity of labor to seek out contracts that pair them with equivalently skilled persons. In the present model, by contrast, the value of some inputs is enhanced by combination with others via their influences on demand.

It is evident that results of the models in this paper are not necessarily robust to alternative specifications of the production (demand) function. Certainly, for example, one could posit functions in which input cost reductions have an insufficiently large quality enhancing effect to lead to higher quality and/or lower variety. At least in the absence of systematic empirical research, it is quite difficult to know what the appropriate production function for entertainment or other information goods is.

Also, of course, the real environments within which firms in these industries function are far more complex than the models of this paper can represent. In the animated movie case, for example, the transition to CGI technology after the mid-1990s was accompanied by competitive challenges from three other studios--Warner, Paramount, and Dreamworks—to Disney's historical domination of the animation genre. Trade reports suggest that this competition contributed to a bidding up of labor prices for top Hollywood animation talent after 1995, followed by an apparent deflation in this balloon after the late 1990s (Eller, 2002; Associated Press, 2001). Those reports are consistent with the cost increases we observe for 2-D movies after 1995. Another factor is likely to be the "learning-by doing" time it takes to develop CGI technology, including the diffusion of skills into the labor market.

Nevertheless, the cost increases in at least CGI movies appear to have persisted. It is not clear how any model that does capture the dynamic element of the competitive process could explain the persistence of higher budgets for the movies made with the "cheaper" CGI technology relative to 2-D movies without appeal to similar arguments to those of this paper.

In conclusion, we hope that this analysis has opened a door to further theoretical and empirical research on the process of information good production and the effects of technology on quality, variety, and social welfare.

Among issues of interest for future research is how changing distribution technology, such as the digital transmission of movies to theaters instead of the cumbersome physical process of shipping thousands of expensive prints, will affect quality and variety, and whether larger studios or independents will benefit most. Lower marginal costs of distribution would appear to have an ambiguous effect on product variety and quality, because while lower marginal costs encourage entry, other things equal, they also increase economies of scale, and thus the potential for greater industry concentration. Other distribution technologies, such as DVD vs. VHS, embody quality into marginal costs; the effect of these changes on quality and variety are also not evident.[15]

A related empirical project that we currently have underway is an investigation of how technological change in movie production has affected levels of Hollywood investment in different movie genres (eg, action vs. drama) since the 1970s. Our working hypothesis is that one reason for a long term shift in Hollywood's production resources toward action, science fiction, and similarly violent genres is that production investments in those genres have become relatively more attractive to studios because cheaper as well as demand-increasing high technology special effects can be more productively employed in them. Technology has provided endless ways to commit spectacular death and destruction, but what can special effects do for a first kiss?

[15] Although the technology question is not directly addressed, the analysis of Berry and Waldfogel (2003) offers useful insights into these questions. The framework of the monopolistically competitive models in this paper is not very useful for addressing marginal cost issues since a fixed aggregate demand results only in price changes without quality or variety differences.

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Appendix A: Animated theatrical feature film data

Figures 1 and 2 and the accompanying text discussion are based on the EDI database, the standard resource for the entertainment industry. EDI reports a total of 5684 movies released in the U.S. from 1988 to 2002 (not including reissues), of which 145 were labeled as "animated," 74 of the latter released between 1998-2002. The figures and text discussion are based only on the 2666 EDI movies (86 of which were animated) for which production cost information, in addition to box-office results, were reported. (Excluded from the analysis were 197 reissues, 16 of which were animated. Animated movie reissues accounted for 5.9% of all animated box-office receipts from 1988-2002).

All production costs made by EDI are estimates, and are based on a variety of industry sources.

Movies without production cost information were overwhelmingly less successful at the boxoffice, indicating that they tended to be much lower budget films. For all non-animated EDI movies released from 1988 to 2002, those with production cost information accounted for 91% of total U.S. box-office receipts earned by all movies in the database. Animated EDI movies with production cost information accounted for 96% of all box-office receipts earned by animated movies over the same period. Thus, the movies excluded from our analysis were relatively insignificant in economic terms.

Appendix Table A-1 summarizes information supporting Figures 1 and 2, and the related text discussion. Coding of the animated films by type of production technology was conducted by an expert in film animation in conjunction with the *imbd.com* Internet movie data base. Movies labeled as CGI include 4 films that combined CGI with at least some significant live action. The 2-D category includes 4 movies that combined 2-D with at least some significant live action, two "stop motion" features, two movies that combined stop motion with live action, and one movie that combined 2-D with CGI, but was predominantly 2-D. Combining animation with live action tends to increase production costs due to problems of coordination, but at least after the mid-1990s, animation in general has been more expensive to produce than live action. Thus, effects on production cost averages from including or excluding these films appear to be relatively minor. The four CGI movies which combined live action with animation cost an average of $96 million., while the six movies that combined 2-D or stop motion with live action cost an average of $50 million. Cost comparisons between CGI and 2-D movies are thus not materially affected by the inclusion of these films.

Appendix Table A-1: Financial and related information for animated and non-animated theatrical feature films: all movies with production cost information, not including reissues 1988-2002.
(financial data in million current $)

Year	All Movies			Animated Movies		
	Number Released	Average Production Cost	Average Boxoffice	Number Released	Average Production Cost	Average Boxoffice
1988	204	10.3	16.4	4	21.6	64.0
1989	277	10.2	14.7	3	12.3	37.6
1990	192	15.9	22.3	4	11.5	17.0
1991	197	16.1	21.4	2	27.5	84.0
1992	174	18.3	24.9	6	18.5	42.3
1993	149	16.6	25.4	3	15.8	20.0
1994	141	23.3	30.7	4	29.6	84.6
1995	163	23.7	29.4	4	33.8	93.2
1996	179	23.6	26.6	4	55.5	70.7
1997	170	29.0	33.7	3	49.3	52.7
1998	168	30.9	34.1	6	68.3	99.7
1999	216	30.3	37.7	8	54.5	93.7
2000	167	36.1	44.6	13	57.6	52.7
2001	151	38.4	52.0	10	57.8	79.6
2002	118	42.4	59.4	11	57.8	66.5
Total*	**2666.0**	**61653.0**	**79793.5**	**85.0**	**3814.7**	**5631.9**
Average**	**177.7**	**23.1**	**29.9**	**5.7**	**44.9**	**66.3**
Totals (98-02)*	**820.0**	**28573.3**	**36184.1**	**48.0**	**2808.5**	**3561.6**
Averages (98-02)**	**164.0**	**34.8**	**44.1**	**9.6**	**58.5**	**74.2**

Year	2D Movies			CGI Movies		
	Number Released	Average Production Cost	Average Boxoffice	Number Released	Average Production Cost	Average Boxoffice
1988	4	21.6	64.0	0	0.0	0.0
1989	3	12.3	37.6	0	0.0	0.0
1990	4	11.5	17.0	0	0.0	0.0
1991	3	27.5	84.0	0	0.0	0.0
1992	6	18.5	42.3	0	0.0	0.0
1993	3	15.8	20.0	0	0.0	0.0
1994	4	29.6	84.6	0	0.0	0.0
1995	3	35.0	60.3	1	30.0	191.8
1996	4	55.5	70.7	0	0.0	0.0
1997	3	49.3	52.7	0	0.0	0.0
1998	4	70.0	86.2	2	65.0	126.7
1999	6	42.2	60.6	2	91.5	192.9
2000	12	45.8	45.7	1	200.0	137.7
2001	5	37.6	30.9	5	78.0	128.4
2002	8	46.4	42.1	3	88.0	131.6
Total*	**72.0**	**2617.7**	**3626.1**	**14.0**	**1197.0**	**2005.8**
Average**	**4.8**	**36.9**	**51.1**	**0.9**	**85.5**	**143.3**
Totals (98-02)*	**35.0**	**1641.5**	**1747.6**	**13.0**	**1167.0**	**1814.0**
Averages (98-02)**	**7.0**	**46.9**	**49.9**	**2.6**	**89.8**	**139.5**

* For financial data, totals indicate aggregates for all movies
** For financial data, averages indicate averages among all individual movies