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

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Abstract

Empirical evidence shows that producers of information products (TV programs, movies, computer software) may respond to potentially cost saving technological change by *increasing* 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 common assumptions about consumer demand and production technology, a monopolist is in fact induced to increase first copy investments as a result of either what I 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.

INTRODUCTION

I motivate this paper by reporting 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 did indeed lead to a dramatic industry shift to CGI technology. The great majority of all major animated films released since *Pocohantas* (1996) have reportedly used CGI technology (Associated Press, 2001). To be expected, the number of animated movies increased, rising from 2.3% of all releases over the 1988-1995 period to 2.9% of movies released from 1996-2002.[1]

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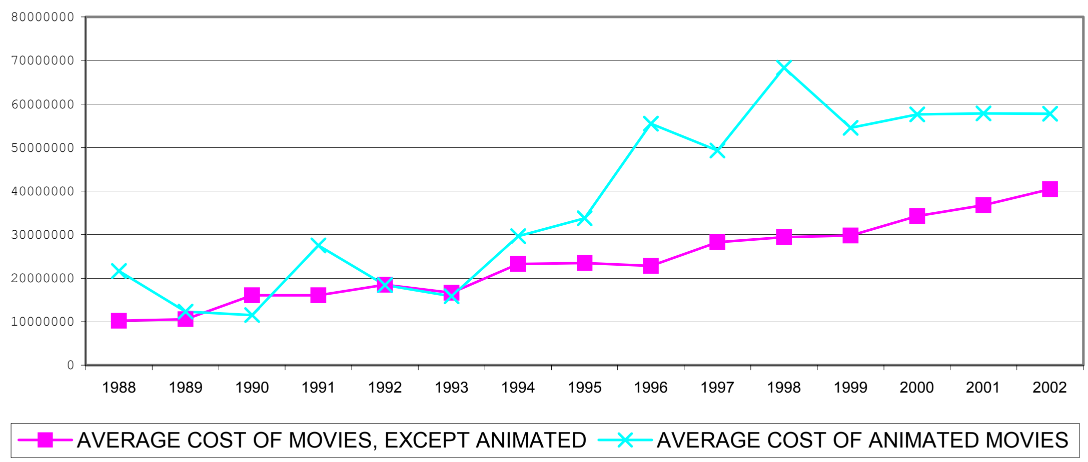
[1] Based on the EDI database, the standard resource for the entertainment industry. EDI reports 6170 movies released in the U.S. from 1988 to 2002, of which 189 were labeled as “animated.” From 1988 to

Trends in animated film production costs, 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, have risen much faster than production costs of non-animated movies.[2]

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



A handful of the higher budget post-1995 animated productions, most of 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), but many of the most expensive have been the CGI entries, including *Monsters, Inc* (2001, $115 million), *Dinosaur* (2000, $200 million), and *Finding Nemo* (2003, $80 million).[3] Overall, while cost differences have recently narrowed, movie producers

1995, non-animated releases averaged 343 per year, compared with. 459 from 1996 to 2002, an increase of 34.0% compared to an increase of 65.8% in animated productions.

[2] Figure 1 is based only on movies for which production costs estimates were available, approximately 40% of the total of the 6170 movies reported by EDI from 1988 to 2002. Of the 189 animated films listed in the data base, 98, or 51.9%, had production cost data. The great majority of animated movies are produced and released by the 7 major studios, and cost trends for only these movies are very close to those for all movies released in the U.S. Since movies without production cost data typically earn very low box-office revenues, it is evident that they have relatively low costs and are relatively insignificant in economic terms.

[3] EDI data base; Graser (2003). We had production technology information readily available from the trade press for about 20 animated movies produced after 1995. These data suggest no significant cost differences between 2-D and CGI movies.

switching to the “cheaper” computer-generated technology have chosen to spend more--not less--on their productions.

How can we explain these developments in animated movie investments?

Though inspired by movies, I address broader questions in this paper about the effects of technological change on information production. In general, producers of information goods make decisions not only about how many different products to make, and on what prices to charge for them, but also on how much to invest in the “first copy” of each product. Essentially, first copy investments are the central determinant of the quality of information products. Examples include investments in computer software product development, the production costs of movies or television programs, and the creation of newspaper or magazine content. There are such huge variations in product quality in these information industries that just counting up the number of available movies, TV programs, or computer programs, etc., has little meaning as a measure of industry output or variety.

Ultimately, there is a tradeoff between product quality and variety in information product markets because of the economies of scale implied by first copy investments in combination with typically low marginal costs of distribution. An individual software developer, for example, could respond to a rise in demand either by producing a larger variety of different software programs, or by simply spending more money to improve upon the program or programs already being offered. In either a monopoly or a competitive market with entry, the quality and variety of products will be determined by some balance between the cost pressures of economies of scale and the consumer demand for variety.

How technological change affects product quality and variety has evident implications for market structure in information industries. For example, if cost-reducing or quality-enhancing technological advances raise the relative advantage to increasing investments in existing software programs vis a vis expanding software program variety, those technologies may increase tendencies toward monopoly in these industries, possibly through strengthened network effects.

Beyond 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 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 declares 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 production costs seem to climb relentlessly. From 1975 to 2002, for example, average production costs of MPAA-member produced movies 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] A large increase in demand due to the development of pay TV and video media has fueled these changes, but production technology has greatly advanced over this period as well. Another information industry in which rising costs have accompanied dramatic technological advance is computer games. Investments per game are reported to be rising dramatically.[5] Available data for Korean game production show that from 1999 to 2001, average development costs per game rose by 118%. Average development time per game rose by 28% and the number of people involved per game rose by approximately 53%. (Korean Game Development and Promotion Institute, 2002).[6]

The tradeoffs between set up costs, quality, and variety in differentiated product industries have long been recognized and studied in the economic literature (Rosse, 1967;

[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] See, for example, summaries of Screen Digest (2003, March), and Spectrum Strategy consultants (2002)
[6] These percentages are derived by the author by averaging the increases over six types of games separately analyzes in the Korean study.

Lancaster, 1975; Spence, 1976, Spence and Owen, 1977, Dixit and Stiglitz, 1977). Later authors have developed endogenous quality models in which quality can be enhanced by increasing sunk, or setup, costs. Shaked and Sutton (1987) develop such a model in which 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. In a recent paper, Berry and Waldfogel (2003) apply a similar model 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 with market size they find in the case of restaurants, a product in which quality primarily depends on variable costs.

Other frameworks have been used to investigate the tradeoffs between the quality and variety of products with endogenous setup costs and constant marginal costs of production or distribution. Economides (1989) considers these tradeoffs in a model that represents product space along a straight line. Waterman (1991) 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 monopoly producer of media products and uses it to explain the tendency for motion picture distributors to increase budgets rather than produce larger numbers of movies.[7] Economides (1993) shows similar tradeoffs between product quality and variety in a circular model framework that emphasizes the role of advertising, but without direct application to media products.

[7] See Owen and Wildman (1992) for a survey of program choice 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 their 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 a progression of increasingly spectacular special effects that clearly enhance our enjoyment of movies--*Close Encounters of the Third Kind (1992), Twister (1996), Men in Black (1999), Harry Potter and the Sorcerers Stone (2001)*, among many in a long list. Basically, these technologies, some of which result in very expensive productions, 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.

In an attempt to better understand the effects of technological advance in information industries, I offer three theoretical models representing alternative market structures and assumptions about production inputs. I do not attempt with these models to develop general results for the effects of technological change on product quality or variety. Rather, I simply hope to demonstrate that with plausibly defined demand and production conditions, the effect of either cost-reducing or quality-enhancing technological change can be increased production investments, and not necessarily greater product variety.

In the first model to follow, I 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, I consider a two variable input case for the monopoly case. Finally, I consider a monopolistically competitive industry in which firms employ a single input in a Salop-style circular model. In that model, both quality and variety can change.

THE MODELS

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, $Q = (J\text{-}\alpha P)E^{\beta}$; $P = price$; $\alpha > 0$; E = number of explosions; c_E = constant cost per explosion; J and α are demand parameters, 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 demand with respect to more and more of them. Total production investment is $K = c_E E$..

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

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

(3) $E^* = [P(J- \alpha P)\beta / c_E]^{1/(1-\beta)}$

(4) $K^* = c_E E^* = [P(J- \alpha P)\beta]^{1/(1-\beta)} c_E^{--\beta/(1-\beta)}$

The effects of cost reducing and quality enhancing technologies can be separately considered in this model. I interpret the effects of cost-reducing technology to simply work through the parameter c_E. That is, a lower c_E means that an explosion with the same audience appeal is cheaper. I interpret the parameter β to measure the effects of quality enhancing technology. That is, the audience demand function w.r.t. E shifts upward if β rises.

To understand equilibrium effects of technological change, we are interested in dE^*/dc_E, dK^*/dc_E, $dE^*/d\beta$ and $dK^*/d\beta$. To evaluate these derivatives, we need only consider (3) and (4), since P^* is independent of c_E or β.

It is easily shown from (3) and (4) that $dE^*/d\beta > 0$ and thus, $dK^*/d\beta > 0$. As we would expect; quality enhancing technology increases incentives to invest. More interesting is the result that both dE^*/dc_E and dK^*/dc_E are unambiguously negative in this model. A lower cost of explosions, that is, increases the use of explosions as we expect--but also, they serve to increase the 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. The positive investment effect is reduced for lower values of β, but it remains unambiguously positive for all $0 < \beta < 1$.

A numerical illustration

A simple example can compare the potential effects of quality-enhancing and cost-reducing inputs in the monopoly case. The first row of Figure 2 shows that for an initial case, the marginal value of the first explosion in a given movie is \$8. Consistent with the demand function in Model I, there are diminishing returns to audience demand from including additional explosions.[8] For this example, we also assume that the cost of explosions in the initial case is $7.

Figure 2

Illustration of the effects of technological change: the single input monopoly case

Number of explosions	1st	2nd	3rd
Marginal value, initial case	$8	$6	$4
Marginal value, enhanced value	$16	$12	$8

The result for the initial case is that one explosion will be used at a cost of $7, since the producer can increase demand for the movie by $8 with one, by only $6 for the second. Now, however, consider a quality-enhancing technological change. As indicated in the second row, the marginal value of explosions jumps to those on row three of the table, due to technological advance in the realism of explosions from computer enhancement. In this case, three explosions will be used, at a total cost of $21. The number of explosions used in the movie thus triples, as does the amount of money spent on them.

Consider now a cost-reducing technology for explosions. That is, say the same explosion becomes only half as expensive to conduct, the cost dropping from $7 to $3.50 each. The producer's response in this case is also to increase explosions from one to three. Total movie expenditures increase in this case as well, though only from $7 to $10.50.

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

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8 A conceptually equivalent, but more complex example using the actual demand function in Model I can be constructed.

Model II: Two Input Monopoly

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

Define:

$$(5)\ \ \Pi = P(J-\alpha P)E^{\beta} S^{\gamma} - c_E E - c_S S,$$

where S = number of stars, and c_S is the constant cost of stars. Assume that γ, the elasticity of demand w.r.t. the number of stars, is between 0 and 1. In this model, then, demand is defined in the form of a standard Cobb-Douglas function; in effect, the number of consumers who watch the movie is "produced" by the combination of inputs. Also assume that $\beta + \gamma < 1$. Finally, for tractability, take the simple case of $\gamma = \beta$.

Maximizing w.r.t. to P, S, and E yields:

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

$$(7)\ \ E^* = c_E^{(1-\beta)/(2\beta-1)}\, c_S^{[\beta/(2\beta-1)]}\, (P^*\beta)^{[(2\beta-1)/(1-\beta) + (1-\beta)/\beta)]}$$

$$(8)\ \ S^* = c_S^{(1-\beta)/(2\beta-1)}\, c_E^{[(\beta/(2\beta-1)]}\, (P^*\beta)^{[(2\beta-1/(1-\beta) + (1-\beta)/\beta)]}$$

$$(9)\ \ K^* = c_E E^* + c_S S^*$$

Again, as we would expect, total differentiation shows that $dE^*/d\beta$ and $dS^*/d\beta$ are positive, as is $dK^*/d\beta$. That is, a higher elasticity of demand w.r.t. either explosions or stars unambiguously increases production investments. We also find, as we would expect, that dE^*/dc_E and dS^*/dc_S are unambiguously negative. Furthermore, dK^*/dc_E, and dK^*/dc_S are 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 interaction effect between S and E. In particular, a fall in c_E results in more explosions being used, but even though this in itself induces the producer to substitute away from stars into explosions, the net effect is to also increase the number of stars used, and thus total spending on stars. This 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 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.

This "more-more" result for input use contrasts with other explanations that have been offered 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 consequences of a "weakest link" increase on the margin with the quality of other inputs (See, for example, Kremer, 1993). In a sociological analysis of labor inputs into motion picture productions, Faulkner (1987) argues that cumulative career attainments are governed by propensities to contract among equivalently skilled persons. In the present model, by contrast, the value of some inputs is enhanced by combination with others through their influences on demand.

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 reduce, total production investments.

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). For simplicity and tractability, only one input, explosions, is assumed.

In this 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 one. 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 I define as the distance in product space between that consumer's location and X_j, and (2) a vertical dimension, E_j, which comparable to the earlier models, I again let be an indicator of product quality, represented simplistically by the number of explosions in the movie. Specifically, I define:

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

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

Profits for firm 1 are then:

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

Solving (11) for x_{12} and substituting into (12), then differentiating (12) w.r.t. P_1 and E_1, then 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, while the investment measures, E^* and K^*, are increasing in β. 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)-(16) 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 before, but at exactly the same rate as the rise in investments, neutralizing the effects on entry.

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, it remains constant as investments, and thus product quality, rise.

DISCUSSION AND CONCLUSIONS

The theoretical models introduced in this paper show that under reasonable 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, or at least not increase, as a result of these technological advances. The feature of the models driving these results is that all inputs appear in both the firm's demand and cost functions. Even a straightforward cut in the wholesale price of one 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.

These results are not necessarily robust to alternative specifications of demand and production functions. Also, of course, the real environments within which these industries function are far more complex than the models can represent. In the animated movie case, for example, it is evident from trade reports that a competitive challenge to Disney's historical domination of the animation genre in the mid-90s by Warner, Dreamworks, and other major studios using CGI technology contributed to the bidding up of labor prices for top Hollywood talent, followed by an apparent deflation in this balloon after the late 1990s (Eller, 2002; Associated Press, 2001). Our models do not capture this dynamic or other strategic aspects of studio competition.

Nevertheless, the models employ fairly standard production and demand functional forms. They provide a rationale for an apparent tendency in information industries for production investments to increase in response to technological change, perhaps at the expense of greater product variety. They also suggest insight into why even apparently straightforward cost-reducing production technologies may not open information industries to independent, low-cost producers to the extent that observers seem to expect. The reason is that large scale producers may be able to take relatively greater advantage of the advances for increasing the quality, and thus the attractiveness, of their products. As a secondary point, the two-input monopoly model suggests an understanding of why cost reductions in some inputs in information production can actually lead to increased use of all inputs, ultimately resulting in higher production investments.

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