The Impact of Technology on the Quality of Information

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ABSTRACT
When new technologies for production and dissemination of information emerge and are adopted, we see a dramatic increase in the quantity of information that is made available for consumption. However, the impact of these technologies on the quality of information is unclear. In this paper we develop a framework for the process of information production and use it as the basis for an economic model that captures a publisher's decision to produce information. This economic model is used to study the impact of a new technology on the supply of information that is produced in terms of both its quality and quantity. Our results show that reduction in costs and relaxation of capacity constraints lead to an increase and decrease, respectively, in the quality of articles produced by a publisher. We also find that the relaxation of the capacity constraints has a more profound impact on the supply of articles to the publishers, while the reduction in costs has a similar impact on the articles that are chosen for publication. These insights can be exploited to develop incentive mechanisms and policies to further increase the quality of information being produced.

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I.7.4 [**Document and Text Processing**]: Electronic Publishing; K.4.4 [**Computers and Society**]: Electronic Commerce; K.6.0 [**Management of Computing and Information Systems**]: General - Economics

General Terms
Management, Economics,

Keywords
Information production, information quality, economic model

1. INTRODUCTION
One of the most profound consequences of the digital revolution is the exponential growth in the amount of information that has become readily available and accessible to end consumers [8]. One of the factors responsible for this is the advances in how information processing, storage and communication technologies have significantly changed the way information is produced and disseminated.

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For example, the traditional medium used by publishers of encyclopedias was numerous volumes of books. However, the emergence of CD ROM technology resulted in the replacement of the traditional medium (i.e., printed volumes) by digital media (i.e., CD ROM) due to a drastic reduction in the costs of producing as well as the price for purchasing the information goods,[1] while simultaneously increasing the richness of the content (with audio and video multimedia content in addition to text and pictures). The evolution of the encyclopedia does not end here. Once the Internet was adopted as medium of choice by leading encyclopedia producers, new encyclopedias emerged that used the Internet as the primary medium. This was followed by the creators to further create systems that use the new technology. For example, novel technologies such as the Wiki have enabled the creation of Wikipedia [12].

This new (digital) mode of content creation and publishing is drastically different from traditional modes for an encyclopedia. As a point of comparison, the *Britannica Ultimate Reference Suite 2006 DVD*, which combines articles of the regular *Encyclopædia Britannica*, the *Britannica Student Encyclopedia*, the *Britannica Elementary Encyclopedia* and the *Britannica Book of the Year*, has just over 100,000 articles, whereas Wikipedia currently has over 1.1 million articles in the English language edition alone. While one may argue about the relative quality of the articles in these disparate encyclopedias [7], one thing is certain – there is at least an order of magnitude difference in the number of articles between the old and the new media.

While, some may argue that the growth in the amount of available information is an overall benefit to society (i.e., "the more the better" perspective), we also need to consider the negative consequences of the ongoing phenomenon, since they may potentially outweigh the benefits. Consider the scenarios illustrated in Figure 1, which depict changes in the distribution of the quantity of information in terms of the quality of information when there is some (fixed) increase in the quantity of information. The line at T_0 and T_1 represents the distribution of information content before and after the adoption of new technology respectively. The area between the two lines (T_0 and T_1) represents the overall increase in quantity of information and has the same magnitude in both graphs. In the worst case scenario

[1] The costs of producing encyclopedias dropped from $300-400 to $1.50 for the publisher and the price dropped from $1500-$2200 to $50 for the consumer [6].

(Figure 1a), the increase in the quantity of lower content is relatively greater than the increase in the quantity of higher quality content, and consequently the signal-to-noise ratio worsens since finding high quality content amidst the greater quantity of low quality content is more difficult. The more favorable scenario (Figure 1b), in which the increase in the quantity of high quality information is greater than that of low quality information, results in a better signal-to-noise ratio.

While the above issues are important unresolved research problems, the literature on information goods does not tackle this problem directly. Most of the extant literature studying information goods focuses on the issues of pricing [e.g., 11] and bundling of information goods [e.g., 1] due to negligible marginal costs, social and legal issues such as copyright and piracy [e.g., 2], and issues related to multi-channel management [e.g., 5]. While the extant literature provides valuable insights with respect to our understanding of the economics of information goods, they fail to fully consider the impact of new technologies in their entirety. For example, while such studies take into account the change in the quality of information consumed due to new technology, they do not look at the impact of technology on the quantity and quality of the information that is produced and available.

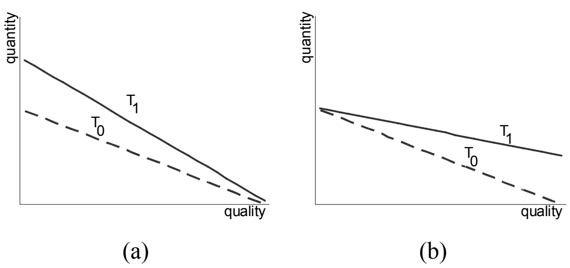


Figure 1: Possible Change in Quality of Information Supply

The purpose of this paper is to study the impact of new information and communication technologies on the supply side of the information revolution. More specifically, we study how the quality and quantity of information that is made available for production and consumption changes due to the adoption of a new technology in the production of information contents. We focus on analyzing the impact of two aspects of a new technology, namely the reduction in the costs associated with producing information and the reduction of storage and/or transmission costs which are manifested in the relaxation of time and space constraints hitherto imposed by older technologies.[2]

Using agent-based simulations we analyze the impacts of reducing costs of the articles and the relaxation of capacity constraints at both the firm (or content publisher) level and at the aggregate channel level (or the content genre). We find that the reduction in costs leads to an increase in the quality of articles published by an individual channel while the relaxation of capacity constraints leads to an increase of the same. Furthermore, the relaxation of capacity constraints has a more profound impact on supply of articles to the channels than the reduction in production costs, while a reverse effect is observed on the articles chosen by the channels for publication.

This paper is organized as follows. We first present the conceptual framework that illustrates the process of information production – conceptualization, production, publication and distribution. Section 3 develops an economic decision model of content production to analytically study the impact of new technology. Numerical results are presented to further gain insights in section 4. Finally, we conclude the paper with discussions and implications.

2. THE PROCESS OF INFORMATION PRODUCTION

Our illustration of the evolution of the encyclopedia in the introductory section helps us conceptualize the life-cycle of information production. In this section we formalize a framework that illustrates the process of information production and the role of technology within the process. By identifying the aspects of the process that are directly affected by the technology employed, we will be able to observe how changes to the employed technology will impact the process and consequently the quality and quantity of information that is the outcome of the process. The process of information production can be formulated as a four-step sequence (Figure 2).

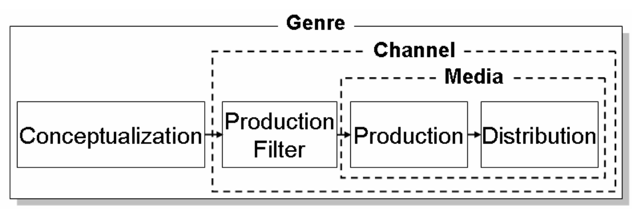


Figure 2: Process Model of Information Production

We define an article as the unit of information that is taken through each step of the production process. An article belongs to a *genre*, which is a socially recognized type of communicative action and is identified by its purpose and shared characteristics of form [9]. The *purpose* of a genre is to define the type of content (or the type of articles) and the *form* of the genre defines the typical format and presentation of the said content. The scope of a genre can be relative. Examples of broad genres include news, cinema, and fiction; while finer-grained examples genres include sports news, action movies, and science fiction. In the first step of the production process, an article is *conceptualized* by the creators (or authors) of the article. At this stage, the article need not be in the final form that is made available to the end consumers, but is rather more of an idea or initial draft. The acceptable form of the article at this stage is also determined by the genre. For instance in the news genre, an article at this stage may be an idea for an news story, while for cinema or fiction, an article at this stage would be a draft of a manuscript. After this stage, the article is submitted to a *channel* (i.e., a publisher) which is an entity (or a person or an organization) that decides which

[2] It may seem obvious that the reduction in the above mentioned costs leads to an increase in the quantity of information being created. But the change in the quality of information is more difficult to predict. While the reduction in production costs may allow the production of content that was previously too expensive to produce resulting in an increase in high quality information, the relaxation or elimination of time and space constraints allows the publication of all information that is conceptualized without a check on the quality resulting in an increase in lower quality information. The impact of new technologies on the quality of information available for consumption is therefore quite unclear.

articles are to be produced and takes the responsibility for the costs of producing articles in the final form that is to be distributed for consumption. For example, the *Wall Street Journal* would be a channel that publishes information content for the financial/market news genre. There are typically multiple channels within a genre[3].

When an article is submitted to a channel, it goes through the second stage of the production process namely the *production filter*. The production filter is the channel's mechanism that determines whether it will produce a submitted article. This decision is made based on the costs and the expected returns of the articles in addition to other characteristics of the channels, which will be further detailed later. For example, within the cinema genre, 20th Century Fox (i.e., the channel) receives many scripts from playwrights. The channel will evaluate the scripts to decide which ones to actually produce.

If the channel decides to produce the article, the article proceeds to the third step of the production process which is the *creation* stage. The conceptual form of the article is converted into a form that is suitable for sale and/or consumption and the channel incurs all the costs associated with the creation of the article. At this stage the channel chooses the appropriate distribution medium or media, which is determined by the form dictated by the genre, as noted above. For the news genre, this would entail the conversion of an idea for a news story into the actual news story in a form that will be broadcasted. Similarly, for the cinema genre it would entail the creation of the final cut of the movie.

In the final step of the production process, the article is replicated and *distributed* to the end consumers using the selected distribution media. The choice of medium is determined by the richness of the media that is required by the genre and/or the channel [3]. Different media use different technologies and afford differences in format (i.e., digital vs. analog), level of personalization, number of cues, whether the content is pushed from the channel to the consumer or pulled by the consumer from the channel etc. Further, these primary characteristics of media may impact important information production and consumption characteristics such as the ease of reproduction, ease of search, ability to archive etc. All these characterized also affect the creation or distribution processes. In the cinema genre, the media that could be employed for distribution include VHS, DVD, theatrical releases and the Internet[4].

[3] This is not to say that a channel only produces articles within a particular genre. A channel may indeed publish articles from one or more genres. However, for simplicity we limit our analysis and discussion to a single genre for the remainder of this paper.

[4] This framework is generally applicable to most genres, though in some cases, some of these steps might overlap. For example, for certain genres, the conceptualization and filtering may occur simultaneously or the creation and distribution may be indistinguishable, as is the case with most textual content available on the Internet. Furthermore, the conceptualization and creation of content may occur simultaneously before the production filter. In such cases, we can perceive the creation step as the time at which the creator or authors are remunerated by the channel.

Channels may change over time for market competition and/or survival. This evolution is based on the characteristics of the articles that are submitted to the channel as well as the articles that it chooses to publish. The characteristics of articles that are submitted to the channels also evolve over time based on the past publication records of the channels. These evolutionary traits are a result of the feedback of the production process and are described in detail in the following sections.

When a new technology associated with a medium emerges, the genres and channels that employ the medium are affected. At the channel level, the creation and distribution stages are the ones that are directly impacted by the changes due to the adoption of the new technology. Reduction in costs, for example, will lead to lower creation and distribution costs and consequently higher profits (assuming demand does not change). The more subtle but equally important impact is experienced at the filtering stage, where the reduction in costs enters the decision process of the channel and changes the publishing behavior of the channel in terms of which articles they decide to produce. The aggregated change in the behavior of all channels within a genre demonstrates the genre level impact of the new technology. In the following section we develop a simple economic model that represents a channel's production filter and models the decision process of choosing articles for production. This model is first used to identify the primary channel level impacts of adopting a new technology. It is then used as the basis for the numerical analysis to identify further channel level and genre level impacts.

3. AN ECONOMIC MODEL OF INFORMATION PRODUCTION

Based on the conceptual framework of information production in the previous section, we develop an economic model of a channel's decision process. This model highlights a channel's rational behavior with respect to information production.

Each article[5] within a genre can by characterized by its inherent quality and cost. Since the genre determines the type of articles, it also defines the quality parameters that are pertinent to the articles within the genre. We consider genres to be very narrow or restrictive definitions of article types, where the quality of individual articles can be vertically differentiated within the genre. The quality of an article can also be conceptualized as the determinant of the demand of the article. This implies that higher quality articles will have a larger demand than lower quality articles. The cost of an article includes all costs associated with producing the first copy (or instance) of the content in its final form. These costs may include but are not limited to remuneration for the authors or creators, and the costs of the resources such as infrastructure employed in the creation. Channels incur cost based on the media that they choose. The distribution costs are uniform for all articles published by a channel and are independent of the characteristics of the article. For example, printing and/or shipping a 200 page book will cost the same regardless of its content quality!

Each channel that publishes articles in the genre is characterized as having an aspiration level for quality ($\hat{q}_i$), a capacity ($\hat{n}_i$) and a budget ($\hat{c}_i$). $\hat{q}_i$ represents the channel's quality threshold – the

[5] For expositional clarity, we use the subscript *j* for the article and the subscript *i* for the channel.

lowest quality of articles that the channel is willing to publish. The capacity $\hat{n}_i$ is the upper limit of the number of articles that the channel is willing or able to publish in each time period. This is determined by the time and space constraints of the channel, which are largely determined by the nature of the media that is used by the channels. For example, the number of pages of a magazine is relatively fixed across issues. The budget (or cost threshold) $\hat{c}_i$ represents the maximum cost that channel is willing to incur per article. The budget can also be conceptualized as $\hat{c}_i\hat{n}_i$ for the channel at a given point of time.

In each time period, each channel i receives a set of n_i articles (i.e., the supply) from which it will select the $\hat{n}_i$ articles to publish. For simplicity, we can assume that the supply set for each channel is unique (i.e., the same article is not submitted to more than one channel during the same time period). A profit maximizing channel will only want to produce and publish a subset of the supply set that will maximize its expected profit given its capacity, quality and cost thresholds. If all articles produced by a channel are sold at price p_i per article, at a distribution and replication cost of d_i per article, the expected revenue from an article j can be expressed as $f_i(q_{ij})p_i$, where $f_i(q_{ij})$ is the expected demand for the article j published by channel i and can be assumed to be an increasing function in q_{ij} based on our prior definition of quality. Although the expected demand is a function of price in classical micro economic, we model expected demand as a function of quality as the publishers of information goods compete on quality and not on price. Within a genre, most information goods are priced at the same level (for example, book prices, movie tickets etc.) and the quality of the article (book or movie) determines the demand. Therefore, the expected profit for article j can be expressed as $\pi_{ij} = f_i(q_{ij})(p_i - d_i) - c_{ij}$ where c_{ij} is the cost for producing the article j. A channel's problem can formulated as the following integer program (see Figure 3).

Objective Function:

$$\underset{x_{ij}}{\text{Max}}\, \pi_i = \sum_{j=1}^{n_i} \pi_{ij} x_{ij} = \sum_{j=1}^{n_i} \left[f_i\left(q_i^*\right)\left(p_i - d_i\right) - c_{ij} \right] x_{ij} \quad \forall j \in \left[1, n_i\right]$$

q_i* is an increasing function of the quality of articles published by the channel

Constraints:

1. Quality Constraint: $\left(q_{ij} - \hat{q}_i\right) x_{ij} \geq 0$
2. Budget Constraint: $\sum_{j=1}^{n_i} c_{ij} x_{ij} \leq \hat{n}_i \hat{c}_i$
3. Capacity Constraint: $\sum_{j=1}^{n_i} x_{ij} \leq \hat{n}_i$

Decision Variable:

$x_{ij} = 1$, if article j is chosen for publication by channel i,
$x_{ij} = 0$, otherwise

Figure 3: A Channel's Optimization Problem

The channel will select a subset of its supply set of articles that will obtain the maximum profit (Objective Function). The first constraint represents the quality constraint that will allow the selection of only those articles whose quality is greater than the minimum allowable quality level (i.e., the quality threshold $\hat{q}_i$). The second constraint represents the budget constraint that will allow the selection of a set of articles whose cumulative costs are within the channel's budget ($\hat{c}_i\hat{n}_i$). Finally, the capacity constraint will ensure the selection of a maximum of $\hat{n}_i$ articles. The decision variable x_{ij} is set to 1 if the article i is chosen for production/publishing, and 0 otherwise. This problem can be reduced to a knapsack problem which can be solved using dynamic programming [13].

It is reasonable to assume that authors or creators of articles will self select into channels in a way that will maximize the probability of their article getting selected while at the same time maximizing their returns. This would imply that an author will submit her articles to channels that have quality aspirations that are close to that of her article and to channels that will offer the highest remuneration, or have a sufficiently large budget to produce her article. We also assume that there exists a positive correlation between the cost and quality of an article. Since authors are remunerated based upon the expected returns from their articles which is determined by the quality of their articles, higher quality articles will cost more than lower quality articles. Furthermore, the resources and infrastructure related costs of articles are made in order to improve the quality of the articles. These assumptions are made in order to differentiate the supply set of articles of the channels. If all channels receive the same supply set of articles, the same set of articles will be chosen for publication by all channels irrespective of their cost or quality constraints. In this situation, only those articles with the highest quality and lowest cost will be selected by all channels. Therefore, we limit the quality of the articles in the supply set of a channel i with quality threshold $\hat{q}_i$ to $[\hat{q}_i - \delta_q, \hat{q}_i + \delta_q]$. We also assume that the cost c_{ij} of an article j is correlated with its quality q_{ij} and is limited to the interval $[q_{ij} - \delta_c, q_{ij} + \delta_c]\ \forall i$.

3.1 Evolution of Channels and Authors

Channels have two types of incentives to evolve over time. The first incentive is to stay in the market. Channels unable to publish a sufficient number of articles in consecutive time periods are not part of the market and will therefore change their policies in order to increase their publishing rates. The second incentive for channels to evolve is to increase profits. Channels will alter their policies in order to increase their profits over time. This policy change is realized by either incrementally increasing or decreasing the quality threshold $\hat{q}_i$, as the cost threshold and capacity are exogenous.

A channel i is unable to publish to its maximum capacity ($\hat{n}_i$) if there is a large discrepancy between its cost and quality thresholds. Channels with high quality thresholds and low budgets are typically unable to publish to their full capacity. In order for these channels to stay in the market, they decrease their quality thresholds so that they can publish a sufficient number of articles in each time period.

On the other hand, channels also have the incentive to increase their quality threshold in order to obtain higher profits. Channels with large budgets and low quality thresholds can increase their quality thresholds and publish articles of higher quality at no additional costs and obtain higher profits.

The information production process not only provides a feedback to the channels, but also to the authors of the articles. The supply set of articles in each time period can therefore evolve based on the past publishing records of a channel. Furthermore, since the supply of articles for each channel is dependent on a channel's quality threshold, as channels evolve so does the supply set of articles for each channel and the overall supply of articles at the genre level. The evolution of both channels and the articles submitted to them are summarized in Figure 4.

In the following section we examine the impact of technology on the cost and quality of articles selected by channels in each time period. In order to isolate the effects of adopting a new technology, we keep the consumption (or demand) and conceptualization (or supply) constant.

Channel Evolution:

For a channel i at every time period

If $\sum_{j=1}^{n_i} x_{ij} \le \hat{n}_i$ for τ consecutive time periods

    Decrement $\hat{q}_i$

Else

    Increment $\hat{q}_i$ if the number of articles that can be published does not decrease.

Article Evolution:

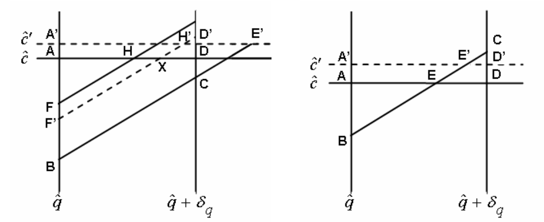
Adjust the average quality of articles submitted to a channel i based on the average quality of articles published by the channel in the past θ consecutive time periods.

Figure 4: A Channel's Optimization Problem

3.2 Reduction in Cost of Production

New technology is adopted by channels when it improves efficiency, reduces the costs of their current processes, and when it creates opportunities that were previously prohibitive. The adoption of a new technology under these circumstances will therefore reduce the costs incurred by the channel and result in higher profits. Other indirect implications include changes in the supply set due to reduced costs, which lead to changes in the articles that are selected by the channel. Consider a channel i with a supply set of n_i articles. If the adoption of the new technology leads to a reduction of $\varepsilon\%$ of the costs of each article in the supply set, i.e., $c'_{ij} = (1-\varepsilon)c_{ij}\ \forall j = 1..n_i$, this is equivalent to an increase of $\varepsilon\%$ in the cost threshold of the channel i.e., $\hat{c}'_i = (1+\varepsilon)\hat{c}_i$.

The impact of reduced costs on the quantity and the quality of articles is determined by the additional articles that satisfy the cost and quality constraints as a consequence of the effective increase in the cost threshold. There are two possible scenarios depending on whether or not the channel is able to produce to full capacity. *First*, consider a channel i which publishes $\hat{n}_i$ articles under the original costs (Figure 5a). The reduction in costs does not have any impact on the number of articles it published, as such a channel will not be able to increase the number of articles it publishes due its capacity constraints. The articles in the supply set that satisfy the cost and quality constraints are enclosed in the area ADCB (the feasible region).[6] The $\hat{n}_i$ articles that maximize the objective function are enclosed in the area BCDHF. When the costs of the articles are reduced, this channel will still produce $\hat{n}_i$ articles, but the new feasible region is the area A'BCD', and the new subset of articles selected for production is enclosed in the area BCD'H'F'. The reduction in costs leads to the inclusion of the additional articles enclosed in the area AA'D'D, and consequently the new selection replaces the articles enclosed in the area FHXF' in the original selection with those enclosed in XH'D'D. From the figure, we can clearly see that the quality of articles in XH'D'D is greater than the quality of articles in FHXF', and therefore the average quality of the new selection set is greater than that of the original selection set.



(a) Full Capacity (b) Not Full Capacity

(Horizontal axis: quality; Vertical axis: costs)

Figure 5: Increase in Quality of Articles due to the Reduction in Production Costs

Second, channels that publish fewer than $\hat{n}_i$ articles with the original costs experience an increase in the quantity of articles they publish when costs are reduced. Let $\tilde{n}_i < \hat{n}_i$ be the number of articles published by such a channel under original costs, which is equal to the number of articles in the supply set that satisfy the cost and quality constraints (Figure 5b). The articles in the supply set that satisfy the cost and quality constraints are enclosed in the area AEB and A'E'B for the original costs and the reduced costs respectively. When the costs are reduced, a larger number of articles (enclosed in the area A'AEE') will satisfy the cost constraint since the cost threshold is higher. If this increase in the number of articles is $\Delta\tilde{n}_i$, then the number of articles that the channel will select for production is $\tilde{n}'_i = \min(\tilde{n}_i + \Delta\tilde{n}_i, \hat{n}_i)$. $\Delta\tilde{n}_i$ is increasing in ε, since the greater the reduction in the costs, the larger the new cost threshold will be and consequently the greater the number of articles that satisfy the cost and quality constraints. The impact on the quality due to reduced costs is determined by the quality of the articles that are added to those selected with the original costs. The additional $\Delta\tilde{n}_i$ articles that the channel selects for production are enclosed in the area A'AEE' and the new selection set is enclosed in A'E'B. The average quality of the articles enclosed in A'E'B is clearly greater than the average quality of the articles in the original selection (enclosed in AEB), due to the inclusion of higher quality articles (enclosed in A'AEE').

The increase in the average quality of articles is determined by the increase in the quality of the additional articles that satisfy the cost and quality constraints (enclosed in the areas A'D'DA and AE'EA in Figure 5a and b respectively). The upper limit of the average quality of the articles published by a channel is $\hat{q}_i + \frac{1}{2}\delta_q$, which occurs when the articles that are selected for production are uniformly distributed over the interval $\left[\hat{q}_i, \hat{q}_i + \delta_q\right]$.

3.3 Relaxation of Capacity Constraints

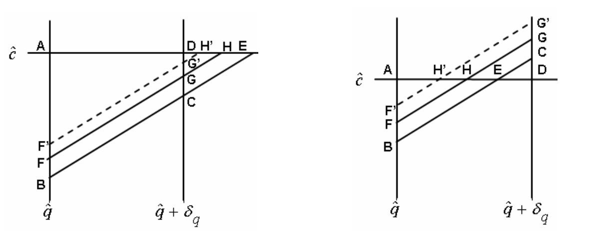
The capacity constraints of channels are primarily determined by the nature of the medium they employ. The medium dictates that amount of storage (in terms of space and/or time) that can be used by the channels at a given points of time. New technologies (such as digitization of audio/video) significantly reduce the costs associated with storage (as well as space and/or time limitations)

[6] The supply set of the articles in Figure 5 and 6 are bounded by the four lines $c = \hat{c}$ (the cost threshold), $q = \hat{q}$ (the quality threshold) and lower bound of the costs of the articles in the supply set $c = q - \delta_c$ and the upper bound of the quality of the articles in the supply set $q = \hat{q} + \delta_q$ as described in the assumptions above.

associated with traditional media, consequently relaxing the capacity constraints for channels that adopt the new technology.

When the capacity of a channel i is increased from $\hat{n}_i$ to $\hat{n}'_i$, the quantity of the articles that it publishes will increase if it originally publishes $\hat{n}_i$ articles and $\tilde{n}_i \geq \hat{n}'_i$ where $\tilde{n}_i$ is the number of articles in the supply set that satisfy the cost and quality constraints. If $\tilde{n}_i < \hat{n}'_i$, it will publish all articles that satisfy the cost and quality constraints. Therefore, the number of articles published by the channel is $\min(\tilde{n}_i, \hat{n}'_i)$, and consequently the increase in quantity of articles published by a channel will increase with $\hat{n}'_i$ as long as $\tilde{n}_i \leq \hat{n}'_i$.

Since there is no change in the subset of articles selected by channels that publish less than $\hat{n}_i$ articles, the increase in capacity will not result in any change in the average quality of articles produced by these channels. Additionally, certain channels such as the one illustrated in Figure 6a will not experience a change in the average quality of the articles that they publish. The articles in the supply set that satisfy the cost and quality constraints are enclosed in the area ABCD. The set of $\hat{n}_i$ articles that maximize the objective function under the initial capacity constraint is enclosed in the area FGCB, and the set of $\hat{n}'_i$ articles that maximize the objective function when the capacity is increased in enclosed in the area F'G'CB. The additional $\hat{n}'_i - \hat{n}_i$ articles that are selected by the channel are enclosed in the area FGG'F' and are uniformly distributed over the entire quality range $\left[\hat{q}_i, \hat{q}_i + \delta_q\right]$, and therefore the average quality of the channel does not change. However, for channels, such as the one represented in Figure 6b, the average quality of the articles published by the channel will decrease. Under the initial conditions, the articles that satisfy the cost and quality constraints are enclosed in the area AEB. The $\hat{n}_i$ articles that maximize the objective function are enclosed in the area FHEB and when the capacity is increased, the $\hat{n}'_i$ articles that maximize the objective function are enclosed in the area FH'EB. The additional $\hat{n}'_i - \hat{n}_i$ articles that are selected by the channel are enclosed in the area FH'HF. These articles have lower quality than those originally selected by the channel, and will contribute to lowering the average quality of the articles published by the channel.



(a) No change in Average Quality (b) Decrease in Average Quality
(Horizontal axis: quality; Vertical axis: costs)

Figure 6: Impact of Relaxation of Capacity Constraint on the Average Quality of Published Articles

Therefore the change in the average quality of articles produced by a channel is determined by the quality of the new articles that are selected for production. As described above, the quality of the additional articles is always less that the quality of the articles in the original selection set. The magnitude of the increase in capacity determines the increase in the number of new articles. As the number of new articles increases, the quality of these new articles decreases, and consequently the average quality of the articles produced by the channel decreases.

4. NUMERICAL ANALYSIS

In addition to the above mathematical analysis the following numerical analysis using simulations is done for a number of reasons. Firstly, the analytic results presented above identify general trends in the behavior of channels in a single time period, but these behaviors are not uniform across all the channels and cannot be generalized and are therefore insufficient to predict genre level impacts. Simulations have been found to be particularly relevant when the focal phenomenon is non-linear [4] as is the case with the different channels and their impact at the genre level. Furthermore, the above analytic analysis does not incorporate the feedback of the information production process to the channels, and can therefore not provide insights into impacts over time. Secondly, simulation studies have been successful in identifying the relationship between micro-behavior (at the channel level) and macro-dynamics (at the genre level). We have been able to identify the rules that regulate the behavior at the channel level; however the effects of these rules are unobservable at the genre level since the behaviors are not uniform. Using simulations, we will be able to identify the impact of the individual channels on the genre as a whole [10]. Thirdly, simulations have been used since it is challenging to obtain the empirical data at the various levels of analysis [4]. Quality being a very subjective measure cannot be very accurately quantified across a number of channels from real world data. Similarly identifying the different thresholds for individual channels is also challenging to obtain. Furthermore, different channels adopt technologies at different points of time, and it is difficult to accurately identify the exact time of the transitions and isolate the impact on the quality and quantity of information produced by that channel and extrapolate it to the genre level. Finally, simulations allow us to relax some of the restrictive assumptions made in the mathematically analysis, such as the continuity of the distribution of the supply of articles and linear relationship between the costs and the quality of the articles.

Matlab 7.1 was used for the simulations and the following numerical analysis. For simplicity, we normalize all cost and quality values over the interval [0,1]. For each run of the simulations, the initial distribution of channels was generated for 100 combinations of cost and quality thresholds. Each combination of the cost and quality thresholds is represented by a single channel i with cost threshold $\hat{c}_i \in [0,1]$ and quality threshold $\hat{q}_i \in [0,1]$. The cost and quality thresholds of the 100 channels are uniformly distributed over the $[0,1] \times [0,1]$ space. The quality thresholds of the channels were updated every t_u time periods based on the outcomes of the previous t_u time periods. If the channel i publishes less than $\hat{n}_i$ articles for t_u consecutive time periods, the quality threshold $\hat{q}_i$ is decreased where as if it publishes $\hat{n}_i$ articles and can increase its quality threshold and continue to publish $\hat{n}_i$ articles for t_u consecutive time periods, the quality threshold $\hat{q}_i$ is increased The profit generated in each time period by a channel is also carried over to its budget for the following time period. For each run, the equilibrium is reached when the channels cease to evolve for t_e consecutive time periods (where t_e is a multiple of t_u). The values of t_u and t_e are set to 5 and 15 respectively.

In each time period the supply set for each channel comprises of 100 articles, i.e. $n_i = 100\ \forall i = 1,..,100$. We relax the assumption of the continuous and uniform distribution of articles in the supply set and use normal distributions for the articles in the supply set. For a channel i, with quality threshold $\hat{q}_i$, the supply set comprises of a draw of n_i articles from $N(\hat{q}_i, \sigma_q)$ (i.e., $q_{ij} \sim N(\hat{q}_i, \sigma_q)\ \forall j = 1,...,n_i$). The cost for each article j in the supply set of channel i is drawn from $N(q_{ij}, \sigma_c)$ (i.e., $c_{ij} \sim N(q_{ij}, \sigma_c)\ \forall j = 1,...,n_i$). The values of n_i, σ_q and σ_c are set to 100, 0.1 and 0.1 respectively for all the simulations. The following results are based on the average values for a 1000 simulation runs.

In the base case, the capacity was set to 10, i.e., $\hat{n}_i = 10$ $\forall i \in 1,..,100$. To study the impact of the reduction in the production costs of the articles, the costs of the articles in each supply set were reduced by 30%, 60% and 90%. The impact of increased capacity is studied by setting the capacity of the channels to 40, 70 and 100 (i.e., 4, 7 and 10 times the original capacity).

Figure 7 shows the distribution of the channels at equilibrium for the base case. In the first time period, there is one channel for each combination of the quality threshold and cost threshold. At equilibrium however, the distribution is skewed and we can observe that the number of channels with quality thresholds that are greater than their cost threshold increase. Consequently there is an overall increase in the number of channels with higher quality thresholds.

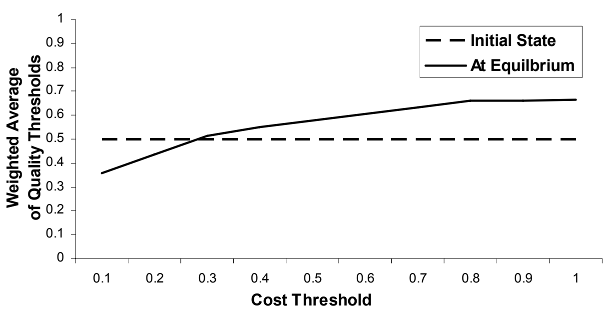
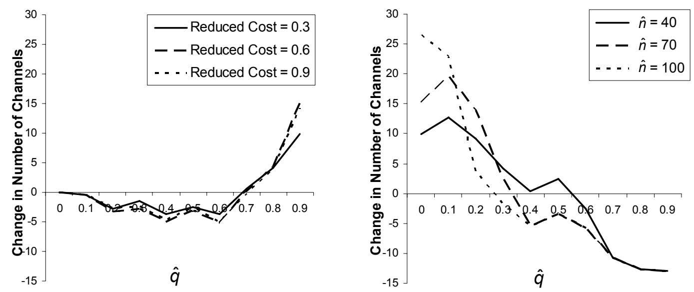


Figure 7: Distribution of Channels at Equilibrium

Figure 8 shows the change in the distribution of the quality thresholds of the channels at equilibrium when the production costs of the articles are reduced and the capacity of the channels are increased. Table 1 shows the average time at which equilibrium is reached (in the base case when capacity is 10 and the costs of the articles are not reduced, the time taken to equilibrium is 16). When the costs are reduced (Figure 8a) we observe an increase in the number of channels with high quality thresholds. From Table 1, we also observe that when costs are reduced, it takes a significant amount to time to reach equilibrium (on average between 16 to 18 time periods), which implies that channels frequently change their quality thresholds. By altering its quality threshold, a channel may experience an increase in its profits in the short term but these are not sustainable for long, thus resulting in volatility in the distribution of quality thresholds.

When the capacity of channels is high, we observe an increase in the number of channels with low quality thresholds (see Figure 8b). We also observe that equilibrium is reached quite rapidly (within 6 time periods, see Table 1). The implications of these results are that when the capacity of channels increase, there is a very rapid and visible decline in the quality thresholds of channels. In other words, profit maximizing channels will tend to reduce their quality thresholds in order to publish as many articles as possible in each time period.



(a) Reduced Cost (b) Increased Capacity

Figure 8: Change in Channels' Quality Thresholds

Reduction in Costs	Time to Equilibrium	Capacity	Time to Equilibrium
30%	16	40	6
60%	18	70	6
90%	16	100	6

Table 1: Time to Equilibrium

4.1 Reduction in Cost of Production

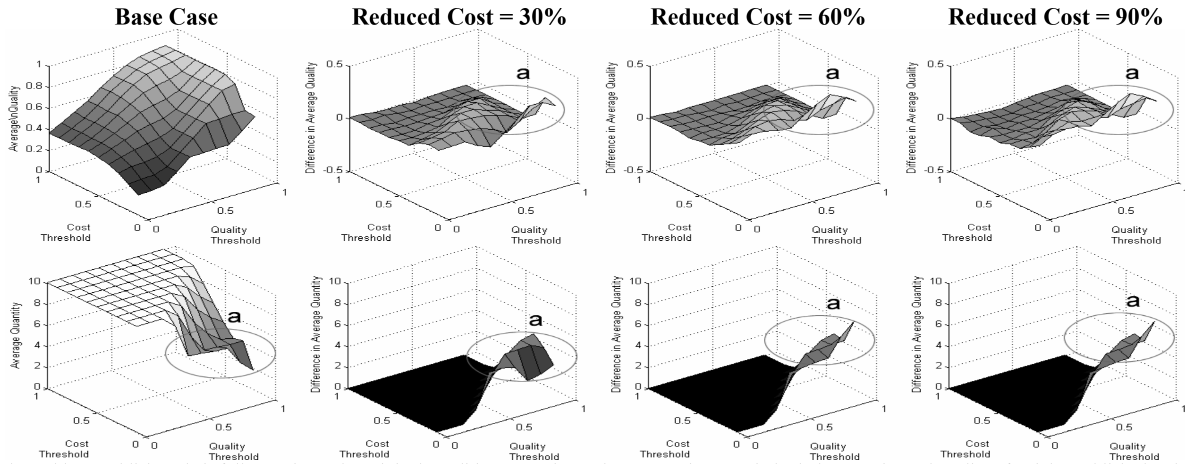
Figure 9 represents the change in the average quality and quantity of articles published by channels at equilibrium. The quality and cost threshold represented by the x and y-axis respectively are the values from the first time period.

The reduction in the production costs of the articles results in an increase in the number of articles published by channels that are unable to publish to their full capacity with the original costs (see 1st row of Figure 9). The magnitude of the reduction in the cost of the articles determines the number of channels that are able to publish to their full capacity. Thus, when the costs of the articles are reduced by a significant amount, the proportion of channels that are able to publish to their full capacity will approach 100%.

The reduction in the production costs of the articles results in an overall increase in the average quality of the articles published by channels (see 2nd row of Figure 9), and this increase is more significant when the percentage reduction in costs of the articles are high (90%) than when it is low (30%). The channels that experience the greatest increase in the average quality of articles that they publish are those with low initial cost thresholds and high quality thresholds. Therefore, channels' ability to increase their quality thresholds does not contribute to significantly increasing the average quality of the articles they publish. The channels that experience an increase in the average quality of their published articles correspond to those channels that are able to increase the number of articles that they publish, and these channels have high quality thresholds and low budgets.

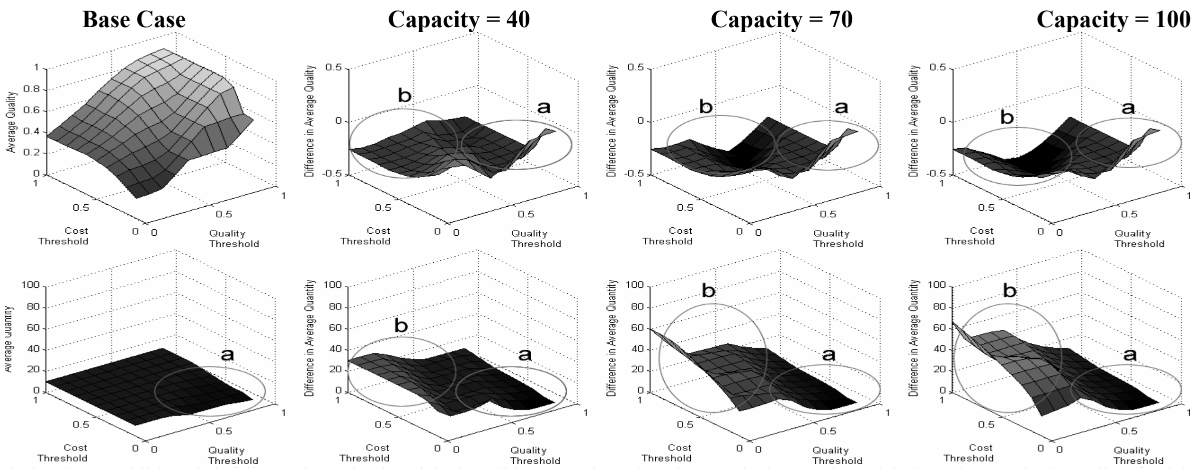
The implications of these results are that channels who previously could not publish to their full capacity due to budget constraints and high quality aspirations are now able enter the market without sacrificing their quality aspirations and publish high quality articles. The reduction in costs also provides incentives for channels to increase their quality aspirations and publish higher quality articles.

Table 2 shows the maximum increase, decrease and mean change in the average quality of articles published by all the channels. We observe that there is a significant increase due to the reduction cost (between 6 to 9%). It is interesting to note that when costs of the articles are reduced by 90%, the maximum decrease in the



(a) Channels unable to publish to their full capacity under original conditions experience the greatest increase in both the quantity and quality of articles published. Channels that publish to their full capacity are not significantly affected.

Figure 9: Reduction in Production Costs



(a) Channels that do not publish to their full capacity under the original conditions experience least increase in the quantity and the least decrease in the quality of articles published.
(b) Channels that publish to their full capacity under the original conditions experience the greatest increase in the quantity and the greatest decrease in quality of articles published.

Figure 10: Increase in Capacity

average quality (4.7%) is more than when the costs are reduced by smaller amounts (30% or 60% with 2.4 and . Channels with high budgets and low quality thresholds decrease their quality thresholds to increase their profits. When the costs of the articles are reduced by 90%, this behavior is more prevalent than when the costs are reduced by 30% or 60%.

	Reduction in Costs			Capacity		
	30%	60%	90%	40	70	100
Max Increase	28.52	39.28	40.16	0.63	0.31	1.33
Max Decrease	2.42	1.83	4.71	34.19	51.25	52.37
Mean	6.07	8.43	7.34	-23.24	-28.54	-30.45

*All values are reported as percentage difference

Table 2: Change in the Average Quality of Articles Published by All Channels

4.2 Relaxation of Capacity Constraints

Figure 10 shows the change in the average quality and quantity of the articles published by the channels at equilibrium when the capacity of the channels is increased from 10 to 40, 70 and 100. The quality and cost threshold represented by the x and y-axis respectively are the values from the first time period.

The increase in capacity results in an increase in the number of articles published by most channels (2nd row of Figure 10). However, this increase in the number of articles published is considerably lower for channels that are unable to publish to their full capacity under the original conditions. These channels have low budgets and high quality thresholds, which are restricted by their budgets and the number of articles they can publish does not increase significantly. Consequently, the decrease in the average quality of the articles published by these channels is relatively lower (1st row of Figure 10).

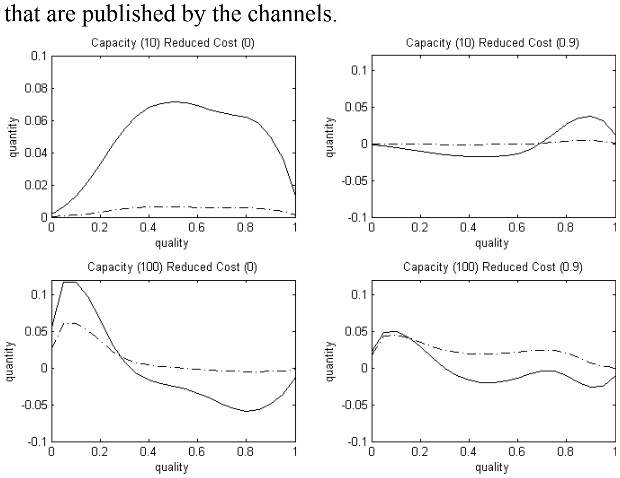
When the capacity of the channels is increased, the average quality of the articles published decreases significantly for all the channels. The decrease is the most significant for those channels with intermediate initial quality thresholds. As there is a pronounced drop in the number of channels with intermediate quality thresholds at equilibrium (Figure 7), these are the channels that decrease their quality thresholds in order to publish a greater number of articles and obtain higher profits.

The implications of these results are that the decrease in the average quality of articles published can be attributed more to the evolution of the channels than the increase in their capacity. The increase in the quantity of articles published by the channels on the other hand, can be primarily attributed to the increase in the capacity of the channels and their budgetary constraints.

Table 2 shows the maximum increase, decrease and mean change in the average quality of articles published by all the channels. We observe that there is a very steep decline in the average quality of the articles published by the channels due to the increase in their capacity. The impact incremental increase in the capacity of the channels on the decrease in the change in the average quality of the channels gradually decreases (a 23% change between $\hat{n}$ =10 and $\hat{n}_i$ =40 compared to a 5% change between $\hat{n}$ =40 and $\hat{n}_i$ =70, and to a 2% change between $\hat{n}$ =70 and $\hat{n}_i$ =100). Therefore, when a channel's capacity is increased beyond a certain threshold relative to its original capacity, the marginal decrease in the average quality of the articles published by the channels is insignificant.

4.3 Aggregate Effects at the Genre Level

At the channel level, we examined the changes in the average quality of the articles published by the channels and the changes in the distribution of the quality thresholds of the channel. At the genre level, we can examine the changes in the distribution of the quality of articles that are published in addition to the changes in the distribution of articles that are available for publishing. Figure 11 shows the impact of reducing the production costs of articles and the increase in the capacity of channels on the distribution of articles within the genre. The solid lines represent the distribution of the articles that available for publishing to the channels and the dotted lines represent the distribution of articles that are published by the channels.



Articles Submitted — . — . — Articles Published

Figure 11: Distribution of Articles

Since authors submit to channels whose quality aspirations are similar to their own, as the quality threshold of the channels change, so does the distribution of articles that are submitted to the channel. With the reduction of costs, the number of channels with high quality thresholds increases, and consequently the authors have to increase the quality of the articles they submit in order to get published. Therefore, the number of high quality articles conceptualized and published within the genre increases when the costs are reduced (see 1st row of Figure 11). Similarly, when the channels' capacity is higher, there is a decrease in the number of channels with high quality thresholds and an increase in the number of channels with low quality thresholds.

Therefore, articles of low quality have a higher probability of getting published and as a result there is considerable increase in the number of low quality articles that are submitted to and published by channels (see 1st column of Figure 11). However, when the both the costs of the articles are reduced and the channels' capacity are increased, the relative increase in the number of high quality articles published is greater than the increase in the number of high quality articles that are submitted to the channels. Therefore, the change in the distribution of the quality of articles in the supply sets of channels is impacted more by the increase in the capacity of the channels, while the change in the distribution of the quality of articles published is impacted more by the reduction in costs.

5. DISCUSSION AND CONCLUSION

This paper examines the impact of the adoption of a new technology or communication medium on the process of information production and the impact on the quality and quantity of information which is the outcome of this process. In order to identify these impacts, we develop a framework that explicates the role technology plays in the creation of information. This framework is then used to develop an economic model for information production for a rational profit maximizing entity (a channel) that produces and disseminates information. From a given supply of information (or articles), the channel selects those articles that maximize its profit under certain capacity, budget and quality constraints. The channels also evolve over time in order to stay in the market and/or increase profitability. The economic model is used to study two of the primary impacts of technology at the channel level and the genre level, namely the reduction in production costs and the relaxation of capacity constraints.

At the channel level, we find that the reduction in the costs of the articles leads to an increase in the number of channels with high quality aspirations, and a subsequent increase in the quality of articles they publish. There is also a marginal increase in the quantity of articles published by certain channels. The relaxation of the capacity constraints on the other hand, leads to an increase in the number of channels with low quality thresholds and a subsequent decrease in the quality of articles published. There is also an obvious increase in the quantity of articles published. At the genre level, we find an increase in the number of high quality articles and low quality articles submitted to channels when costs are reduced and channels' capacities are increased respectively. We also find that the increase in the capacity of the channels has a more significant impact on the distribution of the quality of articles submitted to channels, while the reduction in costs has a significant impact on the distribution of the quality of articles published by channels.

5.1 Implications

The reduction in the production costs of articles has an overall positive impact at both the channel and genre levels. Individual channels are able to increase the average quality of articles they produce and subsequently their quality aspirations, while at the genre level, the distribution of articles submitted to channels and published have a positive shift towards higher quality. The increase in the capacity of the channels has the opposite impact, and leads to a reduction in the channels with quality aspirations as well as an relative increase in the quantity of lower quality articles submitted to and published by channels. The magnitude of the negative impact of the increase is significantly higher than that of the positive impact of the reduction in costs. Consequently, the interaction of these two effects of adopting new technologies is negative.

The increase in the overall quantity of original information available for consumption in each time period implies a decrease in the signal to noise ratio of information. This indicates that searching and retrieving information of any quality is becoming more challenging, and is even more difficult for high quality of information. Consequently, we see in a shift in the manner in which information is consumed, wherein consumers rely more on search engines and aggregators for information to judge the quality of the information they consume. Since the increase in capacity and the reduction in costs results in the increase in the number of articles that are selected by production filters of channels, the responsibility of filtering out high quality content is shifted from the channel to the consumer. Furthermore, the manner in which consumers retrieve information is also changing. While previously, channels pushed content to consumers, an increasing number of consumers are beginning to rely on the pull mechanism to acquire information from various sources.

5.2 Limitations and Future Research

While the model developed in this study gives us some insights, it is based on a number of assumptions which may limit the generality of the results. These assumptions include the inelasticity of the supply and demand of the articles for a channel as well as a fixed revenue model. We also assume that the new technology is adopted by all channels at the same time (while abandoning the existing technology or media), with no sunk costs incurred by either the channel or the consumers. For the numerical analysis at the genre level we assume that initially there is only one channel of each type (i.e. for each quality and cost threshold combination), whereas it is realistic to expect that the density of certain types of channels is greater than others. We leave it for future research to investigate the relaxation of some of these assumptions.

In this paper, we examine a few of the effects of the adoption of a new technology on the production process of information. The emergence of a new technology leads to cascading impacts in the conceptualization of consumption stages, first on the production of information and then on the conceptualization and consumption stages, resulting in changes in the supply of articles received by the channels and the demand of articles respectively. New technologies for broadcast media lead to the emergence of new genres of information. Furthermore, within existing genres, new technology can lead to the accelerated emergence of new channels. When new technology is adopted by existing channels its production process is affected in a number of ways. New medium, while opening up new markets to the channel may also cannibalize the revenue from the existing markets. It may also have other negative impacts, such as the possibility of increasing the ease with which the content can be pirated. Again, we leave it for future research to delve into some of these issues.

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