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Abstract

Technological change is transforming media industries. Digitization lowers the cost of recording, storage, reproduction and distribution, while computer-based editing facilitates higher quality and special effects. With electronic distribution, a vast range of content can be made available to consumers at little cost. Meanwhile, the distribution of industry production and sales appears to be shifting: the late 20th century was the era of the "hit parade", but in the 21st attention has shifted to the "long tail". This paper develops a free entry model of differentiated products with endogenous quality and heterogeneous types to examine the implications of technological change for market

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structure, quality, and the distribution of firms in media industries. This framework can be used to assess current and future trends in media industries.

1 Introduction

Technological change is transforming media industries. In the production of video content—traditionally released as movies and TV programs—and recorded music, digitization lowers the costs of recording, storage and reproduction. Computer-based editing makes higher-quality production possible at lower cost and facilitates new special effects. Distribution on physical media has shifted to more compact, higher quality formats (from VHS to DVD; from vinyl and tape to CD), while electronic distribution over cable and the internet greatly reduces distribution costs. Digitization of television signals permits many more channels to be shown for a given capacity (of radio spectrum or cable infrastructure), and allows images to be broadcast in higher definition. On-line stores can stock a far wider range of products than local retail outlets, and have developed personalized search and recommendation services to assist consumers in finding content tailored to their individual tastes.

These developments are profoundly altering the structure of media industries. The latter part of 20th century was the era of the "hit parade": as the best artists became available to all via recorded media (as compared with live performance), consumer attention focused predominantly on a limited number of top movies, songs, and TV shows. The associated actors and artists became "superstars" and commanded high rents.[1] Now the distribution within media industries appears to be shifting towards the "long tail"[2]: a higher proportion of demand is represented by products that achieve few

[1]See Rosen (1981) for an economic analysis of superstars and the skewness of returns in industries where talent of individual artists is important.

[2]As described by Anderson (2006).

sales individually but which collectively constitute a large part of the market. This fragmentation of demand threatens the profits of media companies, especially those (such as free-to-air television) relying on advertising revenues, being directly related to audience size.

It is unclear how these trends will develop in the future. Will the distributional shift from hits to the long tail continue, or might it be mitigated by the strength of key brands? With technological changes that increase the scope for raising product quality, what is the role of endogenous fixed costs[3] in this story? What is likely to happen to the distribution of firms, and to the superstar phenomenon?

This research aims to investigate the impact of technological change on media industries, in particular as it affects market structure, product mix, quality investment, and the size distribution of firms. To address these questions, we build a model of the media sector (which may be music, movies or video content) capturing its essential features: a large set of differentiated products; fixed costs which are often endogenous, increasing with quality; differences in "talent" or productivity; and the number of products determined by free entry. This model can be used to analyse the impact of cost and demand changes on industry outcomes, and to explore underlying mechanisms, e.g. the role of endogenous fixed costs. The aim of the research is twofold: to investigate which underlying developments can explain past industry trends, and to assess the likely impact of ongoing and potential future changes in technology.

As differentiated product classes, media industries are typically modeled using a locational model of product differentiation.[4] The Hotelling (1929) model is used as the basis for modeling competition between TV broadcasters by Anderson and Coate (2005), Armstrong and Weeds (2007), Peitz and

[3]See Sutton (1991).

[4]An alternative, representative consumer approach to product differentiation is developed by Dixit and Stiglitz (1977). This, however, is rarely used in models of media industries.

Valletti (2008) and Vogel (2009), among others. But this model takes the number of firms to be fixed (duopoly), making it unsuitable for a market where the number of firms is determined by free entry. For this reason, the Salop (1979) model is more appropriate to our purpose. In the Salop model, however, quality is taken to be fixed. The first step in this paper is to endogenize product quality, with a fixed production cost that is increasing in quality (à la Sutton (1991)). There is some modeling along these lines in Armstrong and Weeds (2007), Crampes, Haritchabalet and Jullien (2009), and Seabright and Weeds (2007). With endogenous quality, the Salop model can be used to examine the impact of lower costs (fixed and marginal), a lower cost of raising product quality, and demand changes as captured by the "transport" cost.

In representing firms as competing for customers around a circle, the Salop (1979) model is unhelpful in two respects, however. First, the model is a poor representation of reality in many differentiated product markets. It may be a reasonable approximation for spatial competition (say, between out-of-town stores located around a city), but is less appropriate for heterogeneous product classes such as media content where firms compete directly with all rivals, not just two nearest neighbours. Secondly, the model becomes intractable when firms are heterogeneous in anything other than locations: if, for example, firms have different costs, the symmetry of the model is forfeited and solutions become complex.

One of the motivations for this research is the question of how digitization affects the relative outcomes for different artists or modes of production. Rosen's (1981) analysis of the economics of superstars derives the distribution of outputs and returns from underlying talent differentials and cost functions.[5] To capture this feature in the Salop framework we allow for heterogenous firm "talent", where a talented firm can raise its quality at rela-

[5]Rosen finds the shift from performance to recorded music, as recording costs fell, to increase the skewness of returns: although there is greater entry by low-quality artists, returns to the highest talent—"superstars"—increase enormously.

tively low cost compared with an inferior firm. This difference in productivity may be either intrinsic (a talented individual may generate a quality that is unattainable for lesser artists) or result from the chosen production method (studio production facilitates higher quality than home video recording).

To incorporate heterogeneous firms, the Salop model is generalised so that each firm competes directly with all others, not just its two nearest neighbours. Salop-style models with symmetric competition have been developed by Von Ungern-Sternberg (1991) and Chen and Riordan (2007); these models, or similar functional forms, are used by Brito (2003), Armstrong and Wright (2008) and Germano (2008). In this paper we develop a framework that allows for heterogenous firm types. The challenge is to find a model which is tractable under free entry, with a closed-form solution permitting further (e.g. comparative static) analysis. The model can then be used to examine the strategic choices of different firms and, with free entry of each type, the mix and market shares of talented and untalented firms in industry equilibrium.

The structure of the paper is as follows. Section 2 describes observed trends and developments in media industries, specifically movies and recorded music. Section 3 discusses the modeling approach. Section 4 develops a symmetric model of competition with free entry, initially with homogeneous firms. This is extended to heterogeneous firms in section 5, where a firm discovers its talent type after entry. In section 6 types are known before entry, and the proportion of each in the industry is determined endogenously. With endogenous entry and quality investment, a number of aspects of industry structure can be examined. Section 7 discusses the findings and concludes. An appendix contains longer proofs.

2 Industry trends and developments

This research is motivated by observed trends and on-going developments in media industries. These are illustrated with reference to two industries: movies and recorded music.

2.1 Movie production and distribution

Between the 1950s and 1970s, movie production for theater release suffered greatly from the uptake of television, which reduced theater audiences to a fraction of their pre-television size. In the US, adult per capita theater admissions peaked at around 32 per annum in 1943 and fell to just four per annum in 1971.[6] The early movie industry essentially split in two, with B-movies largely migrating to the television set in a shorter, episodic form, while A-movies continued as primarily theatrical releases. Movie production declined dramatically: output of the seven major Hollywood studios fell by almost half, from an average of 278 new features per annum in 1950-54 to 147 per annum in 1970-74, with a low point of just 85 films in 1977.

After the 1970s the demand for movies recovered substantially, boosted by new, cheaper distribution channels: VHS followed by DVD formats, subscription television,[7] and video on demand (VoD). This era saw the rise of the blockbuster movie, with huge expenditure on production and commensurate salaries to top artists (star actors, and sometimes producers/directors). The location of production also became more concentrated, with Hollywood dominating big-budget movie output and worldwide cinema audiences.[8]

The internet is the next important development in movie distribution, as high-speed broadband connections become widely available. Movie videos

[6] Figures from Waterman (2005), chapter 2.

[7] In the US, restrictions on pay TV were abolished in the late 1970s, clearing the way for the growth of cable television.

[8] In Germany, France, and Italy the box office share of American movies rose from around 30% in the early 1970s to 50% or more in the mid 1990s. In 2001 the US accounted for 44% of world box office revenues.

may be purchased from online stores or downloaded over faster connections. These developments reduce distribution costs and make a wider range of titles available to consumers. It is as yet an open question what the impact will be on the structure of the movie industry. The limited evidence available (see Elberse and Oberholzer-Gee (2008) for an analysis of US video sales) indicates both a growth in the long tail (with the number of titles generating just a few sales each week almost doubling) and the existence of a superstar effect (among the best-performing titles, a smaller number account for the bulk of sales). However, it is unclear how these developments will progress and what will be the impact on movie production and quality investment.

2.2 Recorded music

As in the movie industry, the music scene has historically been dominated by a relatively limited number of stars and hit songs or albums (though tastes and identities change over time). However, since 2000 a marked distributional shift is taking place. There are fewer hit albums: the number of albums achieving sales of 500,000 or more (i.e. gold, platinum, multi-platinum and diamond) exceeded 1,000 in 2002, but fell by more than 40% to around 600 in 2005.[9] Moreover, the top-selling albums no longer achieve such high sales as they once did: in 2000, the top five albums sold 38 million copies combined; in 2005, the equivalent figure had almost halved to 19.7 million. Of course, the music industry as a whole has suffered from the growth of piracy, especially unauthorized file-sharing via the internet, but hits have suffered disproportionately: for comparison, total sales in the music industry fell by a quarter between 2001 and 2005.

Alongside the decline in hit albums, there has recently been a growth in the "long tail": products which achieve a small number of sales individually, but which collectively comprise a larger share of total sales than has historically been the case. In other words, there has been a shift from hits to

[9] Figures from Anderson (2006), chapter 2.

niches: demand is fragmenting into a multiplicity of sub-genres and a wider set of bands. Bands and songs which used to be regarded as "misses" are becoming increasingly important to industry producers and retailers.

Anderson (2006) highlights the role of internet distribution as the cause of this shift. However, it is unclear why this latest innovation in distribution method should have such an effect. The advent of recorded music in the 20th century—an invention that made the output of individual artists available to worldwide audiences—had the opposite effect, generating the superstar or "winner-take-all" phenomenon described by Rosen (1981) and Frank and Cook (1996). This suggests that a more subtle balance of cost and demand changes might be responsible.

3 Modeling media industries

To address these questions, the media sector (whether this is music, movies, or whatever else) must be modeled in a way that captures key industry features, including the cost and demand conditions discussed in section 2. With high fixed and low marginal (per-unit) costs, and both horizontal and vertical product differentiation, media industries tend to be oligopolies. Industry outcomes depend on equilibrium entry, investment (e.g. in quality), and production decisions of competing firms.

In modeling media industries, the following features are important.

Horizontal differentiation. Media content is a highly diverse product class: movie genres include thrillers, comedies, and animation; musical genres include pop, jazz, and classical. Consumers are heterogeneous in their individual preferences, and most have a desire for variety. This entails the desirability of producing a broad range of differentiated products. Certain characteristics of media content are important to particular groups of consumers. For example, consumers tend to have a preference for the output of their home country, reflecting their own language, culture, icons, etc. In addition, some tastes may be narrowly focused (niches), while others appeal to a broad swathe of consumers (e.g. "lowest common denominator" output).

Fixed production costs. Content production costs are largely or entirely fixed: there is a large first copy cost, while thereafter the marginal cost of supplying additional viewers is negligible. This cost function implies that price cannot equal marginal cost in the textbook sense. In conjunction with consumer desire for variety, there is a trade-off between the number of differentiated products (which raises consumer surplus by matching diverse tastes more closely) and duplication of fixed production costs.

Quality and endogenous fixed costs. While being fixed in relation to the number of viewers, production costs tend to increase with higher quality: a movie, say, with greater appeal to viewers typically costs more to produce. In other words, fixed costs are partially endogenous, with important implications for market structure and competition (see Sutton (1991)).

Distribution costs. Distribution and retailing involve some per-unit costs (pressing and delivering a CD or DVD; cinema viewing), but these are typically small compared with the cost of content production. The internet lowers distribution costs in a number of ways. By dispensing with the need for extensive retail floor space, more products can be stocked at lower cost. Electronic distribution reduces the need for physical media to be transported (e.g. downloading a song over a broadband connection rather than purchasing a CD). Search costs may also be lower (see below).

Sunkness and uncertainty for producers. As well as being fixed, production costs are typically sunk: these cannot be recovered if the project is later abandoned (although the possibility of movie sequels and staging of TV series offer some flexibility). In addition, success is highly uncertain: it is difficult to predict which outputs will be popular with consumers. These features make investment risky, and may give rise to option values.

Talent of individual artists. Media content typically has a key input: the artists, be they actors, musicians, or (sometimes) directors. Artists have intrinsic talent, which is largely exogenous but may also require development. Differences in their attractiveness to consumers, and their earning power, can be huge: e.g. A-list / B-list actors; superstars, stars and also-rans.

Consumer uncertainty and search. For the consumer, media content is an experience good: its valuation is uncertain until the product is consumed, or at least sampled. The provision of product information and sampling opportunities is costly, for retailers, consumers, or both. In this environment search and recommendation services are an important aspect of marketing and retailing. Beyond word-of-mouth, consumers have long taken advantage of sampling facilities offered by retailers (traditional book and music stores, cinema trailers) and the media (radio station play, newspaper and magazine media reviews). Online recommendation services (such as Rhapsody for music) and individualized search are a more targeted and potentially wide-ranging approach to this problem.[10]

This paper develops a modeling framework which captures both the entry of horizontally differentiated products and scope for vertical differentiation through quality investment. It incorporates fixed costs, in particular endogenous fixed costs associated with higher quality, as well as distribution costs. In the later sections it allows for talent differences between firms, which may reflect either the intrinsic skill of the artists or different production modes. The particular talent of the individual firm may be uncertain prior to entry, being discovered only afterwards, or may be revealed prior to entry. Through the development of three, related models, the paper examines the implications of each of these features, determining equilibrium outcomes for the number of firms (which may be interpreted as differentiated products or brands), vertical differentiation via quality investment, prices, and the proportions and market shares of low-quality ("basic") and high-quality ("premium") products.

[10] Search-based explanations for the long-tail phenomenon are examined by Brynjolfsson, Hu and Simester (2007), among others.

4 A model of competition with endogenous quality

Each of $N \geq 2$ firms is located at a corner of an N-dimensional polygon. Each corner is connected to every other by a Hotelling line, the length of which corresponds to the mass of consumers between the pair.[11] The total mass of consumers is normalised at 1, thus each pair of firms competes over mass $m = \frac{2}{N(N-1)}$. Unit transport cost is t. When firm k offers utility u_k to consumers, firm i's market share is given by

$$s_i = \frac{1}{N} + \frac{(N-1)}{2t}\left(u_i - \overline{u}_{-i}\right) \tag{1}$$

where $\overline{u}_{-i} = \frac{1}{N-1} \sum\limits_{j \neq i} u_j$.

Utility u_i from consuming product i depends on product quality v_i, advertising intensity a_i, and price p_i as follows

$$u_i = v_i - \delta a_i - p_i. \tag{2}$$

The parameter δ represents the perceived nuisance of adverts. A firm that supplies advertising a receives advertising revenue $R(a)$ per viewer; we assume that there are decreasing returns to supplying advertising, in the sense that R is a concave function. A firm can choose its quality v_i by incurring a fixed cost $\frac{1}{2}\gamma v_i^2$. There is a marginal cost c of supplying each customer.

Timing of the game is as follows. Firms first choose whether or not to enter the market; active firms and consumers locate as described above.[12]

[11] If the lines were instead taken to be of constant length, entry would not reduce average transport costs. In this case a single firm would be socially optimal as entry merely duplicates fixed costs.

[12] The model structure implies that consumer locations are endogenous to the number of firms that enter. Such an assumption may be justified by the marketing experience that consumers have difficulty forming preferences over unknown products (or sets of characteristics), and instead form preferences over the available set of products.

Firms then compete for consumers, simultaneously setting quality v, advertising a, and price p.

Firm i's profit is given by

$$\pi_i = \left(\frac{1}{N} + \frac{(N-1)}{2t}\left(u_i - \overline{u}_{-i}\right)\right)\left(p_i - c + R(a_i)\right) - \frac{1}{2}\gamma v_i^2.$$

Since $p_i = v_i - \delta n_i - u_i$, we can write

$$\pi_i = \left(\frac{1}{N} + \frac{(N-1)}{2t}\left(u_i - \overline{u}_{-i}\right)\right)\left(v_i - u_i - \delta n_i - c + R(n_i)\right) - \frac{1}{2}\gamma v_i^2 \ .$$

Regardless of market share it is a dominant strategy to set $a_i = a^*$ which maximises $R(a) - \delta a$. The corresponding revenue is denoted R^*.

Firm i's best responses in p and v are

$$\begin{aligned} p_i &= \frac{t}{N(N-1)} + \frac{1}{2}\left(v_i + \overline{p}_{-i} - \overline{v}_{-i} + c - R^*\right); \\ v_i &= \frac{1}{2t\gamma}(N-1)\left(p_i - c + R^*\right). \end{aligned}$$

with $\overline{p}_{-i}$ and $\overline{v}_{-i}$ defined similarly as above. With N firms, equilibrium price and quality are

$$p_N = \frac{2t}{N(N-1)} + c - R^* \quad \text{and } v_N = \frac{1}{\gamma N},$$

giving per-firm profit of

$$\pi_i = \frac{1}{N^2}\left(\frac{2t}{(N-1)} - \frac{1}{2\gamma}\right).$$

With free entry, $\pi(N) = 0$ and the equilibrium number of firms is

$$N^* = 4t\gamma + 1, \tag{3}$$

and the free-entry price and quality are

$$p^* = \frac{1}{2\gamma(4t\gamma+1)} + c - R^* \quad \text{and } v^* = \frac{1}{\gamma(4t\gamma+1)}. \tag{4}$$

It can be seen from these results that distribution cost c and advertising revenue R^* (which acts like a negative distribution cost) pass through in full to consumer prices, and have no effect on either the number of firms or quality investment.

4.1 Social optimum

For comparison, we describe the socially optimal number of firms and the quality per firm. Since the welfare effects of advertising are additively separable from the welfare effects of quality and diversity, we can ignore the advertising side of the market.[13] With N firms each providing a product of quality v, social welfare is given by[14]

$$W = v - \frac{t}{2N(N-1)} - N\left(\frac{1}{2}\gamma v^2\right). \tag{5}$$

Given N, the optimal quality choice is $\frac{1}{\gamma N}$, the same as the market equilibrium. One can show that the welfare-maximizing number of firms is

$$N^W = 1 + t\gamma + \sqrt{t\gamma(1+t\gamma)} \tag{6}$$

The market generates more (fewer) firms than is socially optimal for $t\gamma > (<)\frac{1}{8}$; note that competitive equilibrium ($N^* \geq 2$) requires $t\gamma \geq \frac{1}{4}$, which entails excess entry.[15] As $\gamma \to \infty$ (in the limit, quality is fixed) the ratio

[13]The welfare effects of advertising are contentious, and beyond the scope of this paper.

[14]With N firms, each is $\frac{2}{N(N-1)}$ from its rivals, and so a consumer is on average $\frac{1}{2N(N-1)}$ from her nearest product. The expected transport cost is then $\frac{t}{2N(N-1)}$.

[15]The finding of excess entry is a common result in locational models of product differentiation: see Bhaskar and To (2004).

$\frac{N^*}{N^W} \to 2$, as in the Salop model.

4.2 Comparative statics

The model has three parameters of interest: distribution cost c, quality cost γ and transport cost t.

Proposition 1 *Comparative static results for the endogenous quality model are as follows.*
(i) The equilibrium number of firms, N^*, is increasing in t and γ, and independent of c. Similar comparative static results exist for the socially optimal number of firms, N^W.
(ii) Equilibrium price p^* is increasing in c, and decreasing in t and γ.
(iii) Equilibrium quality v^* is decreasing in t and γ, and independent of c.

Proofs are straightward and are omitted.

4.3 Impact of digitization

We wish to assess the impact of digitization. In this framework, digitization may be characterised as some combination of the following effects: (i) a reduction in the per-unit distribution cost, c (digital formats, internet distribution); (ii) a reduction in the cost of raising quality, γ (better special effects, multiple camera angles in sports coverage, speedier news reporting); and (iii) a reduction in transport cost, t (viewer familiarization, lower adaptation costs); this is equivalent to an expansion in market size (globalization).

From the comparative static results above, the following impacts can be determined. A lower distribution cost c reduces prices, but has no other effects. A lower quality cost γ reduces the equilibrium number of firms, and raises both quality and price. This is an endogenous fixed cost effect: with quality being cheaper at the margin, firms invest more and fixed cost increases. This reduces the equilibrium number of firms; in addition, price must be higher to recoup the higher fixed cost. A reduction in transport cost t (or, equivalently, market expansion) reduces the equilibrium number of firms, and increases equilibrium quality and price. Lower t raises the marginal return to quality, inducing firms to invest more, resulting in higher quality and price, and larger endogenous fixed costs. As t falls, competition intensifies; anticipating this, fewer firms enter.

5 Competition with heterogeneous firms

Now suppose that there are two distinct types of firms. In particular, firms differ in the cost of raising quality, γ, with there being two types. Superior firms have a low quality cost parameter γ_L, while inferior ones have a higher quality cost $\gamma_H > \gamma_L$. For simplicity we ignore advertising and its associated revenue in the rest of the paper; as noted above, advertising revenue simply feeds through to lower consumer prices.[16]

Firms do not know their own (or each others') types prior to entry (this assumption is relaxed in the next section). Their common prior is a probability λ of being type L and probability $(1-\lambda)$ of being type H. Firms first choose whether or not to enter; active firms and consumers locate as described in section 4. After entry, firms' types are revealed and they then compete in quality v and price p.

One might expected the two types to choose different prices and qualities; we denote these strategies $\{p_L, v_L\}$ and $\{p_H, v_H\}$ for L- and H-types respectively. With N active firms, a firm of type g expects to face $\lambda(N-1)$ rivals of type L and $(1-\lambda)(N-1)$ rivals of type H.

The market share of firm i of type g is given by

$$s_g^i = \frac{1}{N} + \frac{(N-1)}{2t}\left(u_g^i - \lambda u_L^j - (1-\lambda)\, u_H^j\right). \tag{7}$$

[16] Alternatively, distribution cost c could be thought of as net of advertising revenues.

Its expected profit is

$$\pi_g^i = s_g^i \left(p_g^i - c\right) - \frac{1}{2}\gamma_g \left(v_g^i\right)^2 .$$

For given N, λ, equilibrium strategies are

$$\begin{aligned} v_L &= \frac{1}{N}\frac{(4t\gamma_H - N + 1)}{(4t\gamma_H\gamma_L - (N-1)\,\overline{\gamma})}; \\ p_L &= c + \frac{2t\gamma_L}{(N-1)}v_L; \end{aligned}$$

$$\begin{aligned} v_H &= \frac{1}{N}\frac{(4t\gamma_L - N + 1)}{(4t\gamma_H\gamma_L - (N-1)\,\overline{\gamma})} < v_L; \\ p_H &= c + \frac{2t\gamma_H}{(N-1)}v_H; \end{aligned}$$

where $\overline{\gamma} = \lambda\gamma_L + (1-\lambda)\,\gamma_H$. Equilibrium profits for the two types are

$$\begin{aligned} \pi_L &= \frac{1}{2}\gamma_L v_L \left(\frac{4t}{N\,(N-1)} - \overline{v}\right); \\ \pi_H &= \frac{1}{2}\gamma_H v_H \left(\frac{4t}{N\,(N-1)} - \overline{v}\right). \end{aligned}$$

where $\overline{v} = \lambda v_L + (1-\lambda)\,v_H$.

A firm does not know its type before entering the market. Given the probabilities $\lambda, (1-\lambda)$ of type L, H respectively, and substituting the equilibrium outcomes above, expected profit is given by

$$E\pi = \frac{1}{2N^2\,(N-1)}\frac{(4t\gamma_L - N + 1)\,(4t\gamma_H - N + 1)}{4t\gamma_H\gamma_L - (N-1)\,(\lambda\gamma_L + (1-\lambda)\,\gamma_H)}.$$

The free entry condition $E\pi(N) = 0$ has two roots, $(4t\gamma_L + 1)$ and $(4t\gamma_H + 1)$, and is discontinuous at $\left(4t\gamma_H\gamma_L\frac{1}{\bar{\gamma}}+1\right)$. Taking the smaller root[17] the equilibrium number of firms is

$$N^A = (4t\gamma_L + 1) \tag{8}$$

and equilibrium prices and qualities are

$$v_L = \frac{1}{\lambda\gamma_L(4t\gamma_L+1)}; \tag{9}$$
$$p_L = c + \frac{1}{2\lambda\gamma_L(4t\gamma_L+1)}; \tag{10}$$
$$v_H = 0; \tag{11}$$
$$p_H = c. \tag{12}$$

In equilibrium, the two types of firm supply vertically differentiated products. Inferior (high quality cost) firms do not invest in quality at all and supply the basic product at price equal to marginal cost, while superior (low quality cost) firms supply higher quality products at a higher price.

5.1 Comparative statics

The model has five parameters: distribution cost c, superior-type quality cost γ_L, inferior-type quality cost γ_H, transport cost t and the proportion of superior (L) types, λ.

Proposition 2 *Endogenous quality model.*
Comparative static results for the endogenous quality model are as follows.
(i) The equilibrium number of firms, N^A, is increasing in t and γ_L, and independent of c, γ_H and λ.
(ii) Type L's equilibrium price p_L is increasing in c, decreasing in t, γ_L and

[17]The profit function is monotonically decreasing for $N \in \left(1, \left(4t\gamma_H\gamma_L\frac{1}{\bar{\gamma}}+1\right)\right)$, is positive at the lower bound of this interval and discontinuous at $-\infty$ at the upper bound, thus the smaller root is the first N at which profit reaches zero.

Table 1: Comparative statics in the model with heterogeneous firms

	N	p_L	p_H	v_L	v_H
c	none	+	+	none	none
γ_L	+	–	none	–	none
γ_H	none	none	none	none	none
t	+	–	none	–	none
λ	none	–	none	–	none

λ, and independent of γ_H.
(iii) Type L's equilibrium quality v_L is decreasing in t, γ_L and λ, and independent of c and γ_H.
(iv) Type H's equilibrium price p_H is increasing in c, and independent of t, γ_H, γ_L and λ.
(v) Type H's equilibrium quality v_H is independent of all parameters.

Proofs are straightward and are omitted. The results are summarized in Table 1.

5.2 Impact of digitization

The impact of digitization is similar to that found in section 4, but with price and quality effects occurring for superior firms alone. A lower cost of raising quality has no effect on the choices of inferior firms, but reduces the equilibrium number of firms and raises both the quality and price of superior firms. As before, these effects are due to the endogeneity of fixed costs. Globalization, as captured by a reduction in transport cost, intensifies competition and increases the marginal return to quality, reducing the equilibrium number of firms and increasing the quality and price of superior firms.

6 The model with endogenous entry

Suppose there are two types of firm, untalented (U) and talented (T). These may represent different forms of content provision: low-budget home video (such as that distributed on YouTube) and more expensive studio production, which allows greater scope for quality enhancement. Or they might represent alternative strategies chosen by *ex ante* identical firms: for example, a broadcaster's choice between basic and premium content, where the quality of premium (but not basic) programming may be raised by additional investment.

This model, unlike the previous two, incorporates exogenous fixed costs as well as a quality-related term.[18] An untalented firm pays a fixed cost $F > 0$ to supply a program of minimal quality v_0, normalised at zero.[19] It is unable to raise quality further: since the model above with heterogeneous firms shows that the inferior, high quality cost type does not invest anyway, this assumption is not unduly restrictive. Talented firms have endogenous quality, producing a program of quality v at a total (exogenous + endogenous) fixed cost of $K + \frac{1}{2}\gamma v^2$. To ensure an equilibrium with both types, we require $K > F$. For simplicity, we normalise the per-unit cost $c \equiv 0$: as demonstrated by the two models above, a per-unit cost simply adds to prices and affects no other variables.

Move order in the game is as follows: First, firms discover their types (or choose their production strategy); they then make entry decisions, before competing in prices p and, for the talented type only, quality v.

A firm of type g anticipates that a proportion λ of rivals will be of type T and $(1 - \lambda)$ of type U, with the total number of active firms being $N > 1$.

[18] These exogenous fixed costs, and the difference between them, are require to ensure an equilibrium in which both types are present.

[19] Minimum quality v_0 is assumed sufficient to ensure full consumer participation.

Its market share is

$$s_g^i = \frac{1}{N} + \frac{(N-1)}{2t}\left(u_g^i - \lambda u_T^j - (1-\lambda)\,u_U^j\right).$$

For an untalented firm, profit is given by

$$\pi_U^i = \left(\frac{1}{N} + \frac{(N-1)}{2t}\left(-p_U^i + \lambda\left(p_T^j - v_T^j\right) + (1-\lambda)\,p_U^j\right)\right)p_U^i - F;$$

while a talented firm has profit

$$\pi_T^i = \left(\frac{1}{N} + \frac{(N-1)}{2t}\left(v_T^i - p_T^i + \lambda\left(p_T^j - v_T^j\right) + (1-\lambda)\,p_U^j\right)\right)p_T^i - K - \frac{1}{2}\gamma\left(v_T^i\right)^2.$$

Each type's profit function is concave in its price and, where relevant, quality, thus second order conditions for a maximum are satisfied. Given N and λ, equilibrium prices for each type and equilibrium quality (for talented types only) are given by

$$\begin{aligned} p_U &= \frac{2t\,(4t\gamma - N + 1)}{N\,(N-1)\,(4t\gamma - (N-1)\,(1-\lambda))}; \\ p_T &= \frac{8\gamma t^2}{N\,(N-1)\,(4t\gamma - (N-1)\,(1-\lambda))} > p_U; \\ v_T &= \frac{4t}{N\,(4t\gamma - (N-1)\,(1-\lambda))}. \end{aligned}$$

Free entry conditions for each type ($\pi_U^i = 0$ and $\pi_T^i = 0$) determine N and λ. Taking the positive root for the latter, expressions for N and λ are given by

$$N = \left(4t\gamma\frac{(K-F)}{K} + 1\right); \tag{13}$$

$$\lambda = \frac{F}{(K-F)}\left(\frac{K}{(4t\gamma\,(K-F) + K)}\sqrt{\frac{K}{2\gamma\,(K-F)\,F}} - 1\right). \tag{14}$$

It can be seen that as $F \rightarrow 0$ (with $K > F$), $\lambda \rightarrow 0$: talented types are crowded out. As $K \rightarrow F$ (with $F > 0$), $\lambda \rightarrow \infty$: untalented firms are crowded out. To ensure an interior solution $\lambda \in [0, 1]$ the following parameter restriction is required (with $K > F$ the set is non-empty)

$$t \in \left[\frac{K}{4\gamma (K - F)} \left(\frac{F}{K} \sqrt{\frac{K}{2\gamma (K - F) F}} - 1 \right), \right. \\ \left. \frac{K}{4\gamma (K - F)} \left(\sqrt{\frac{K}{2\gamma (K - F) F}} - 1 \right) \right]. \quad (15)$$

Substituting (13) and (14), equilibrium prices and quality are given by

$$p_U = F \sqrt{\frac{K}{2\gamma F (K - F)}}; \quad (16)$$

$$p_T = K \sqrt{\frac{K}{2\gamma F (K - F)}}; \quad (17)$$

$$v_T = 2 (K - F) \sqrt{\frac{K}{2\gamma F (K - F)}}. \quad (18)$$

Market shares for a single firm of each type are given by

$$s_U = \sqrt{2\gamma \frac{F}{K} (K - F)}; \quad (19)$$

$$s_T = \sqrt{2\gamma \frac{K}{F} (K - F)} > s_U. \quad (20)$$

The total share of talented firms, S_T, is given by

$$S_T = \lambda N s_T = \frac{K}{(K - F)} - (4\gamma t (K - F) + K) \sqrt{\frac{2\gamma F}{K (K - F)}}. \quad (21)$$

Naturally, the total share of untalented types, $S_U = (1 - \lambda) N s_U = 1 - S_T$.

The next sub-section examines comparative static properties of these equilibrium outcomes. As an additional exercise, we look at the impact of a proportionate change in *both* fixed costs, F and K. To assess this, we redefine $F \equiv \mu f$ and $K \equiv \mu k$, where $k > f$. The equilibrium number and mix of firms then become

$$\begin{aligned} N &= 4t\gamma \frac{k-f}{k} + 1; \\ \lambda &= \frac{f}{(k-f)} \left(\frac{k}{(4t\gamma (k-f) + k)} \sqrt{\frac{1}{\mu} \frac{k}{2\gamma f (k-f)}} - 1 \right); \end{aligned}$$

while equilibrium prices and quality become

$$\begin{aligned} p_U &= f \left(\sqrt{\mu \frac{k}{2\gamma f (k-f)}} \right); \\ p_T &= k \left(\sqrt{\mu \frac{k}{2\gamma f (k-f)}} \right); \\ v_T &= 2(k-f) \left(\sqrt{\mu \frac{k}{2\gamma f (k-f)}} \right); \end{aligned}$$

and market shares

$$\begin{aligned} s_U &= \sqrt{2\gamma\mu \frac{f}{k} (k-f)}; \\ s_T &= \sqrt{2\gamma\mu \frac{k}{f} (k-f)}; \end{aligned}$$

$$S_T = \frac{k}{(k-f)} - (4\gamma t (k-f) + k) \sqrt{\frac{\mu 2\gamma f}{k (k-f)}}.$$

6.1 Comparative statics

The model has five parameters: untalented-type fixed cost F, talented-type fixed cost K, talented-type quality cost γ, transport cost t and, allowing for proportionate changes in fixed costs, μ. The proportion of talented types, λ, is now endogenous. The following propositions give comparative static results for equilibrium outcomes of the endogenous quality model.

Proposition 3 *Number of firms.*
The equilibrium number of firms, N, is decreasing in F, increasing in K, γ and t, and independent of μ.

Proposition 4 *Mix of talented and untalented types.*
(i) The proportion of talented firms, λ, is decreasing in μ, γ and t.
(ii) Comparative statics in F and K are ambiguous; subject to the sufficient condition

$$\frac{(4K^2t\gamma - 4F^2t\gamma + K^2)}{(4Kt\gamma - 4Ft\gamma + K)^2}\sqrt{\frac{K}{2\gamma F(K-F)}} > 1, \tag{22}$$

λ is increasing in F and decreasing in K.

Proposition 5 *Prices and quality.*
(i) Type U's equilibrium price p_U is increasing in F and μ, decreasing in K and γ, and independent of t.
(ii) Type T's equilibrium price p_T is increasing in μ, decreasing in γ and independent of t. It is decreasing (increasing) in F for $F < (>)\frac{1}{2}K$, and decreasing (increasing) in K for $K < (>)\frac{3}{2}F$.
(iii) Type T's equilibrium quality v_T is decreasing in F and γ, increasing in K and μ, and independent of t.

Proposition 6 *Market shares.*
(i) The market share of a single untalented firm, s_U, is increasing in K, μ and γ, and independent of t. It is increasing (decreasing) in F for $F < (>)\frac{1}{2}K$.

Table 2: Comparative statics in the model with endogenous entry

	N	λ	p_U	p_T	v_T	s_U	s_T	S_U	S_T
F	–	+ (*)	+	– then +	–	+ then –	–	?	?
K	+	– (*)	–	– then +	+	+	+	?	?
μ	none	–	+	+	+	+	+	+	–
γ	+	–	–	–	–	+	+	+	–
t	+	–	none	none	none	none	none	+	–

* subject to sufficient condition.

(ii) The market share of a single talented firm, s_T, is decreasing in F, increasing in K, μ and γ, and independent of t.
(iii) The total market share of talented types, S_T, is decreasing in μ, γ and t. Comparative statics in F and K are ambiguous.

Proofs are given in the appendix. The results are summarized in Table 2.

6.2 Impact of digitization

We wish to assess the impact of digitization. Digitization may be characterized as some combination of the following effects:

- reduction in fixed costs F and K, either individually, or together via μ (cheaper video storage, editing and transmission);
- reduction in the cost of raising quality γ (better special effects, multiple camera angles in sports coverage, speedier news reporting);
- reduction in transport cost t (viewer familiarization; lower adaptation costs; also market expansion due to globalization).

A reduction in fixed cost for "basic" production F, on its own, increases the total number of firms, as entry by untalented firms is encouraged. If the sufficient condition (22) is met, it can be determined that the proportion of talented firms falls. Untalented firms cut their price, while talented types respond to increased competition from untalented types by raising their quality, thus increasing vertical differentiation. Talented firms first reduce price, but raise it again as F falls further, building their individual market shares throughout.

A reduction in fixed cost for "premium" production K, on its own, reduces the number of firms and results in lower per-firm market shares for both types.[20] If the sufficient condition (22) is satisfied, it can be determined that the proportion of talented firms rises. Untalented firms raise price, while talented firms invest less in quality, reducing vertical differentiation, and first lower then (for further reductions in K) increase their prices.

More clear-cut results are found when both exogenous fixed costs move together. A proportionate reduction via a fall in μ does not alter the total number of firms but increases the proportion of talented types, which then invest less in raising quality, reducing vertical differentiation. With the intensification of competition both types cut prices. Per-firm market share falls for both types, but the total share of talented types increases.

A reduction in the cost of raising quality γ reduces the total number of firms but increases both the proportion and total market share of talented types. Talented firms invest more in quality, increasing vertical differentiation. Prices charged by both types go up, while market per-firm shares for both types decrease.

An increase in market size ("globalization"), as captured by a reduction in transport cost t, reduces the total number of firms and increases both the proportion and total market share of talented types. In this formulation there is no change in quality or in prices of either type, nor in any individual firm's market share.

[20] Note that since the proportions of the two types, λ, also changes, these results are not inconsistent.

7 Discussion and conclusion

By examining and comparing the three models, the effects of three developments linked to digitization can be assessed: cheaper quality, globalization, and lower (exogenous) fixed costs. Endogenous fixed costs play a key role: as described by Sutton (1991), various market developments affect firms' incentive to invest in raising quality, increasing their (endogenous) fixed costs and altering the attractiveness of entry.

If quality becomes cheaper, firms invest more, inhibiting entry and raising quality and price. With heterogeneous types, the second model illuminates the scope for vertical (quality) differentiation. Firms with a relatively high quality cost do not invest in quality at all, preferring to produce basic products. Then, if quality becomes cheaper through digitization, the relatively productive firms invest more and also raise their prices, increasing vertical differentiation and widening price dispersion.

Endogenizing entry of each type, the third model also allows the mix of high- and low-quality products to change. If quality becomes cheaper, the endogenous fixed cost effect reduces entry and increases vertical differentiation (as before), but also raises both the proportion and total market share of high-quality products. Now, with lower entry of untalented firms, reduced competition between basic products permits an increase in their price, as well as in that of high-quality products, implying that price dispersion does not necessarily increase.

Globalization raises the marginal return to quality, tending to induce firms to invest more. With heterogenous firms basic products are left unchanged, thus globalization increases vertical differentiation and price dispersion. In all three models, the endogenous fixed cost effect of globalization is so strong that number of firms actually falls, rather than rising as the market expands. However, when product mix can change, rather than increasing quality globalization instead raises both the proportion and total market share of high-quality products. It would appear that the increased entry of, and competition between, talented firms offsets the increased marginal return to quality resulting from globalization, leaving quality unchanged. However, the high-quality products come to dominate the market – as Hollywood did in the global movie market in the latter part of the 20th century.

Changes in exogenous fixed costs can be examined in the third model. Whether fixed cost reductions affect low- or high-quality firms makes a crucial difference here. A reduction in the former increases the number of firms (as in Salop (1979)), increasing the range of products available to consumers, and may tend to increase the proportion of basic products (the "long tail"), while also increasing vertical differentiation as talented firms respond by raising quality. A lower exogenous fixed cost for talented firms has the opposite effect, reducing the number of firms. This outcome appears to be the result of increased competition between types rather than endogenous fixed costs: talented firms lower the quality of their output, reducing vertical differentiation between these and basic products, which seems to inhibit entry overall. If exogenous fixed costs fall for both types proportionately, talented types gain a larger total share of the market, but again vertical differentiation falls. In this case intensification of competition between the two types causes both to cut prices.

Thus, with its various impacts, digitization may have a number of different effects. It is not inconsistent to find basic products taking a larger share of the market, even while more talented types increase their quality (this may happen when the fixed cost of making and distributing a low quality product – such as home video posted on YouTube – falls). Such an outcome increases the range of products available to consumers while also increasing vertical differentiation between low- and high-quality products. However, other changes associated with digitization, such as lower-cost methods of improving quality, increase vertical differentiation but reduce entry, decreasing the range of products on offer. The precise set of outcomes is sensitive to the nature of the changes brought about by digitization, and may depend on which are the dominant factors. Thus, although explanations may be found for observed trends, such as the rise of the hit parade in the late 20th century and growth of the long tail in the 21st, drawing precise predictions for the future is complex.

This paper has combined entry by horizontally differentiated products, vertical differentiation and endogenous entry by different "talent" types. Since the models are solving using free-entry conditions, firms (in expectation at least) make no more than a normal return. Thus, although the distribution of firms may be skewed, expected returns are not. A possible extension would be to incorporate a complementary input, the artist, which is in limited supply and must be combined with the endogenous quality input (say, high-quality production or special effects) to produce a song or movie. A talented artist might then earn rents, akin to the skewed returns in the superstars literature, which are affected by the costs of other inputs and demand changes. With this extension, the analysis might cast light on the earnings of top artists and producers in the digital age.

8 Appendix

Proof of Proposition 3.

Number of firms, $N = 4t\gamma\frac{(K-F)}{K} + 1 = N = 4t\gamma\frac{(k-f)}{k} + 1.$

$\frac{dN}{dF} = -\frac{4\gamma t}{K} < 0;$

$\frac{dN}{dK} = 4\gamma t\frac{F}{K^2} > 0;$

$\frac{dN}{d\mu} = 0;$

$\frac{dN}{d\gamma} = 4t\frac{(K-F)}{K} > 0;$

$\frac{dN}{dt} = 4\gamma\frac{(K-F)}{K} > 0.$ ■

Proof of Proposition 4.

Proportion of talented types, $\lambda = \frac{F}{(K-F)}\left(\frac{K}{(4t\gamma(K-F)+K)}\sqrt{\frac{K}{2\gamma(K-F)F}} - 1\right) = \frac{f}{(k-f)}\left(\frac{k}{(4t\gamma(k-f)+k)}\sqrt{\frac{k}{2\gamma\mu(k-f)f}} - 1\right).$

$$\frac{d\lambda}{dF} = \frac{K}{(K-F)^2}\left(\frac{\left(4K^2t\gamma-4F^2t\gamma+K^2\right)}{(4Kt\gamma-4Ft\gamma+K)^2}\sqrt{\frac{K}{2\gamma F(K-F)}}-1\right)$$
$$+\frac{K^2}{4\gamma F(K-F)^3}\frac{(2F-K)}{(4Kt\gamma-4Ft\gamma+K)}\sqrt{\frac{2\gamma F(K-F)}{K}};$$
$$\frac{d\lambda}{dK} = -\frac{F}{(K-F)^2}\left(\frac{\left(4K^2t\gamma-4F^2t\gamma+K^2\right)}{(4Kt\gamma-4Ft\gamma+K)^2}\sqrt{\frac{K}{2\gamma F(K-F)}}-1\right)$$
$$-\frac{KF}{4\gamma(K-F)^3}\frac{1}{(4Kt\gamma-4Ft\gamma+K)}\sqrt{\frac{2\gamma F(K-F)}{K}};$$

The signs of $\frac{d\lambda}{dF}$ and $\frac{d\lambda}{dK}$ are ambiguous; a sufficient condition for $\frac{d\lambda}{dF} > 0$ and $\frac{d\lambda}{dK} < 0$ is $\frac{\left(4K^2t\gamma-4F^2t\gamma+K^2\right)}{(4Kt\gamma-4Ft\gamma+K)^2}\sqrt{\frac{K}{2\gamma F(K-F)}} > 1$.

$$\frac{d\lambda}{d\mu} = -\frac{K^2}{4\gamma\mu^2(K-F)^2(4t\gamma(K-F)+K)}\sqrt{\frac{2\mu\gamma F(K-F)}{K}} < 0;$$
$$\frac{d\lambda}{d\gamma} = -4t\frac{KF}{(4Kt\gamma-4Ft\gamma+K)^2}\sqrt{\frac{K}{2\gamma F(K-F)}} - \frac{1}{4\gamma^2}\frac{1}{(4Kt\gamma-4Ft\gamma+K)}\frac{K^2}{(K-F)^2}\sqrt{\frac{2\gamma F(K-F)}{K}} < 0;$$
$$\frac{d\lambda}{dt} = -4\gamma KF\frac{1}{(4Kt\gamma-4Ft\gamma+K)^2}\sqrt{\frac{K}{2\gamma F(K-F)}} < 0. \blacksquare$$

Proof of Proposition 5.

(i) Price of untalented type, $p_U = \sqrt{\frac{FK}{2\gamma(K-F)}} = \sqrt{\frac{\mu fk}{2\gamma(k-f)}}$.

$$\frac{dp_U}{dF} = \frac{K^2}{4\gamma(K-F)^2}\sqrt{\frac{2\gamma(K-F)}{FK}} > 0;$$
$$\frac{dp_U}{dK} = -\frac{F^2}{4\gamma(K-F)^2}\sqrt{\frac{2\gamma(K-F)}{FK}} < 0;$$
$$\frac{dp_U}{d\mu} = \frac{fk}{4\gamma(k-f)}\sqrt{\frac{2\gamma(k-f)}{\mu fk}} > 0;$$
$$\frac{dp_U}{d\gamma} = -\frac{KF}{4\gamma^2(K-F)}\sqrt{\frac{2\gamma(K-F)}{FK}} < 0;$$
$$\frac{dp_U}{dt} = 0.$$

(ii) Price of talented type, $p_T = \sqrt{\frac{K^3}{2\gamma(K-F)F}} = \sqrt{\frac{\mu k^3}{2\gamma(k-f)f}}$.

$$\frac{dp_T}{dF} = (2F-K)\frac{K^2}{4\gamma F^2(K-F)^2}\sqrt{\frac{2F\gamma(K-F)}{K}} < (>)0 \text{ for } F < (>)\tfrac{1}{2}K;$$
$$\frac{dp_T}{dK} = (2K-3F)\frac{K^2}{4\gamma F(K-F)^2}\sqrt{\frac{2\gamma F(K-F)}{K}} < (>)0 \text{ for } K < (>)\tfrac{3}{2}F;$$
$$\frac{dp_T}{d\mu} = \frac{k^3}{4\gamma f(k-f)}\sqrt{\frac{2\gamma f(k-f)}{\mu k^3}} > 0;$$
$$\frac{dp_T}{d\gamma} = -\frac{K^2}{4\gamma^2F(K-F)}\sqrt{\frac{2\gamma F(K-F)}{K}} < 0;$$
$$\frac{dp_T}{dt} = 0.$$

(iii) Quality of talented type, $v_T = \sqrt{\frac{2K(K-F)}{\gamma F}} = \sqrt{\frac{2\mu k(k-f)}{\gamma f}}$.
$\frac{dv_T}{dF} = -\frac{K^2}{2\gamma F^2}\sqrt{\frac{2\gamma F}{K(K-F)}} < 0;$
$\frac{dv_T}{dK} = \frac{(2K-F)}{2\gamma F}\sqrt{\frac{2\gamma F}{K(K-F)}} > 0;$
$\frac{dv_T}{d\mu} = \frac{k(k-f)}{2\gamma f}\sqrt{\frac{2\gamma f}{\mu k(k-f)}} > 0;$
$\frac{dv_T}{d\gamma} = -\frac{K(K-F)}{2\gamma^2 F}\sqrt{\frac{2\gamma F}{K(K-F)}} < 0;$
$\frac{dv_T}{dt} = 0.$ ■

Proof of Proposition 6.
(i) Market share for a single, untalented firm, $s_U = \sqrt{2\gamma \frac{F}{K}(K-F)} = \sqrt{2\gamma\mu \frac{f}{k}(k-f)}$.
$\frac{ds_U}{dF} = (K-2F)\sqrt{\frac{\gamma}{2KF(K-F)}} > (<) 0$ for $F < (>) \frac{1}{2}K;$
$\frac{ds_U}{dK} = \frac{F}{K}\sqrt{\frac{F\gamma}{2K(K-F)}} > 0;$
$\frac{ds_U}{d\mu} = \frac{f\gamma(k-f)}{2k}\sqrt{\frac{2k}{\gamma\mu f(k-f)}} > 0;$
$\frac{ds_U}{d\gamma} = \sqrt{\frac{F(K-F)}{2\gamma K}} > 0;$
$\frac{ds_U}{dt} = 0.$

(ii) Market share for a single, talented firm, $s_T = \sqrt{2\gamma \frac{K}{F}(K-F)} = \sqrt{2\gamma\mu \frac{k}{f}(k-f)}$.
$\frac{ds_T}{dF} = -\frac{K}{F}\sqrt{\frac{\gamma K}{2F(K-F)}} < 0;$
$\frac{ds_T}{dK} = (2K-F)\sqrt{\frac{\gamma}{2FK(K-F)}} > 0;$
$\frac{ds_T}{d\mu} = \frac{\gamma k(k-f)}{2f}\sqrt{\frac{2f}{(k^2\gamma\mu - fk\gamma\mu)}} > 0;$
$\frac{ds_T}{d\gamma} = \sqrt{\frac{K(K-F)}{2F\gamma}} > 0;$
$\frac{ds_T}{dt} = 0.$

(iii) Total shares of talented types, $S_T = \frac{K}{(K-F)} - (4\gamma t(K-F) + K)\sqrt{\frac{2\gamma F}{K(K-F)}} = \frac{k}{(k-f)} - (4\gamma t(k-f) + k)\sqrt{\frac{\mu 2\gamma f}{k(k-f)}}$.
(NB: total share of untalented types, $S_U = 1 - S_T$.)
$\frac{dS_T}{dF} = \frac{K}{(K-F)^2} + \left(\frac{2t\gamma}{K}(2F-K) - \frac{K}{2(K-F)}\right)\sqrt{\frac{2\gamma K}{F(K-F)}};$

$\frac{dS_T}{dK} = (4t\gamma (K - F) + K) \frac{\gamma F(2K-F)}{2K^2(K-F)^2} \sqrt{\frac{2K(K-F)}{F\gamma}} - \frac{F}{(K-F)^2} - (4t\gamma + 1) \sqrt{\frac{2\gamma F}{K(K-F)}}$;
The signs of $\frac{dS_T}{dF}$ and $\frac{dS_T}{dK}$ are ambiguous.
$\frac{dS_T}{d\mu} = -(4t\gamma (k - f) + k) \frac{\gamma f}{2k(k-f)} \sqrt{2\frac{k^2 - fk}{\mu f \gamma}} < 0$;
$\frac{dS_T}{d\gamma} = -4t\sqrt{\frac{2\gamma F(K-F)}{K}} - \sqrt{\frac{F}{2\gamma K(K-F)}} (4t\gamma (K - F) + K) < 0$;
$\frac{dS_T}{dt} = -4\gamma (K - F) \sqrt{\frac{2\gamma F}{K(K-F)}} < 0$. ■

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