When TV Becomes a Stream: Content Decisions of a Video On Demand Service

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Abstract

Entertainment television today is being increasingly consumed via online video on demand (VOD) services. A VOD service is less constrained compared to the traditional (linear) TV in terms of the number of programs it can simultaneously offer, allowing its viewers to watch a program at a time of their choice. On the one hand, offering more programs can dilute the quality of the programs; while on the other, the time flexibility given to the viewers creates an incentive for the VOD service to produce high-quality programs. In this paper, we theoretically study how the 'on-demand' feature affects the number of programs and the investment in their qualities of a monopolist when viewers are heterogeneous in their keenness to watch television programs, their preferred genre (taste preference) and, importantly, their preferred time to watch the programs (time preference). We first show that, when offering the same number of programs, while the linear TV service always offers them at the same quality, the VOD service can offer them at different qualities. When the VOD service offers more programs—utilizing its capacity advantage to better cater to viewer tastes—the offering can comprise both higher and lower quality programs compared to the linear TV. We also find that, while VOD increases consumer welfare, it is not always Pareto-improving because some viewers may only consume a lower quality program. All the results are driven by the heterogeneity in viewer time preferences, and are in line with the real world observations about the content of popular VOD platforms.

Keywords: Streaming platforms, Entertainment industry, Quality, Variety, Disruptive technology

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1 Introduction

Streaming services have now become a key mode of entertainment consumption at homes. Today, the most popular streaming platforms like Netflix and Prime Video are available around the globe. In the U.S., prominent TV networks like NBC and CBS have also metamorphosed into streaming services[1]. A striking feature of such services is the flexibility it accords to viewers that allows them to watch a program at the time of their convenience and hence are referred to as video on demand (VOD) services. Since the consumption of TV became widespread (decades ago), there have been advances in technology that brings content to homes, however the ability of "on-demand" consumption is a significant departure. Such a shift in technology warrants study, especially of what changes viewers may expect to see in the production decisions from service providers—a question taken up in this paper.

TV programs (or content) have been an active area of study in economics and management, primarily to understand the welfare implications of different regulatory choices (Spence and Owen [1977], Steiner [1952], Gal-Or and Dukes [2003]). While the goal here is different, this literature is a guide to features that contribute to viewer welfare. Typically, viewers' utility from watching a program depends on two factors: (i) how the program matches with a viewer's (genre) taste and (ii) the quality of the program, which can be improved through costly investments. With viewers being heterogeneous in taste, the TV literature studied the provision of variety and quality to viewers (see Section 2 for a discussion). VOD services do not face the capacity constraints of TV networks and therefore are better equipped to cater to viewer tastes by offering more programs. Offering more programs however comes at the cost of quality investment in programs, as there are fewer viewers for each program. This is the basic trade-off a service provider faces when they make program decisions.

[1]NBC has a streaming service named Peacock and CBS has a streaming service branded CBS All Access. These services include all the prime-time shows of their parent channels and also some exclusives.

In studying a VOD service, we bring forth a key aspect that previously received no attention- variation in viewers' preference for when they want to watch a program.[2] In other words, we account for the fact that viewers have a preference not only for the content but also for the *time* at which they consume television; and these preferences vary across viewers. With the two preferences independent of each other, the VOD service's ability to make available programs at all times (as opposed to programs made available on a schedule) potentially affects its production decisions. The on-demand service is unaffected by the heterogeneity in viewer time preferences, providing the incentive to make higher quality investments. Further, the viewership of a VOD program, apart from its own genre and quality, is also closely dependent on that of other programs offered as all the programs are available at any given time.

In this paper, we develop a simple analytical model of VOD and linear TV services' program choices that incorporates the key features of viewer demand to understand how they affect the variety and quality of the programs on offer. Specifically, we consider a setting where a monopolist service provider invests in the quality of programs and offers them in two periods. The viewers can watch (consume) a program in both the periods. A program offered belongs to one of two genres (e.g., drama and comedy). The viewers are heterogeneous in their keenness to watch a program (of any genre), their preferred genre (program taste) and the preferred time to watch[3]. Thus, the utility gained from watching a program depends on the program's quality, a viewer's love for its genre and, notably, also the time at which they watch.

Our first result illustrates that a VOD service could offer multiple programs with different (asymmetric) quality investments whereas a linear TV service always offers them with same (symmetric) quality investments. VOD in such a case makes all the viewers

[2]For example, some viewers prefer to watch during daytime (or weekdays) and some during nighttime (or weekends).

[3]We assume symmetric viewer preferences along all the three dimensions. In an extension, we expand the scope to include situations where the time preference is asymmetric, i.e., more viewers prefer watching in one of the periods than in the other.

watch the same (the higher quality) program in their preferred time. Thus it is able to separate the contents for the viewers' preferred and less-preferred periods. Note that this is not possible in linear TV, as the period in which a program is aired is some viewers' preferred period and others' less-preferred period. The result implies that, while we do not expect to see a perceptible difference in quality between two prime-time dramas (say) on traditional TV, the programs offered by a VOD service are likely to be produced through different levels of investment. Our second result is that, in conditions where either service offers the same number of programs, the VOD service's average quality is either higher or equal. While the result is not surprising as the VOD service has an advantage on the time dimension, a more nuanced point is that some of the programs offered could be of a lower quality than in the linear TV offering because of VOD's asymmetric quality investments.

When the VOD service utilizes its capacity advantage to better cater to viewer tastes and offers more programs compared to what a linear TV service would offer, the variety-quality trade-off should decrease the average quality of VOD's programs. However, in the third result, we show that, when the time preference of viewers is relatively strong, the VOD service can offer as many programs (as linear TV would offer) at a higher quality and the others at a lower quality. Not surprisingly, the VOD service's offering always leads to a higher consumer welfare. However, we highlight that the VOD service is not always a Pareto improvement over the linear TV because a portion of the viewers only get to watch a lower quality program in some cases of VOD.

Apart from illustrating the differences, the model predictions are also useful explanations for observations about VOD services by commentators and analysts. As the emergence of VOD services are recent, commentaries and analyses of them often use (like in this paper) the traditional TV service as a reference. A common observation is about how VOD services like Netflix offer more (new and exclusive) programs compared to the traditional TV networks. Commentators have also repeatedly noted that a lot of these programs are of a lower quality.[4] The latter observation could arise from perceiving quality differences among the programs offered by a VOD service or a lower quality of some of its programs compared to TV[5]. However, major VOD services by all accounts have offered programs with significant investments that have also gone on to win major accolades.[6] We illustrate how these observations are consistent with the difference between the program decisions of either service. Research that studies program decisions with a focus on competitive forces and therefore abstract away from the details of program distribution (and viewing) cannot adequately explain observations on difference in quality among the programs offered by a VOD service. Similarly, without unpacking the "on-demand" service provision, observations of lower quality programs on VOD service (compared to TV) cannot be adequately explained.[7] Our paper therefore complements the analytical literature [Jiang et al., 2019] that focuses on competitive forces and informs empirical studies [Godinho de Matos and Ferreira, 2018] of VOD services.

The paper proceeds as follows. We discuss the literature related to this paper in the following section. In Section 3, we describe the model, and solve for the optimal qualities and profits for different TV and VOD offerings in Section 4. Section 5 presents the variety and quality comparisons of TV and VOD program offerings. We extend our model by incorporating asymmetric time preference across viewers in Section 6, before concluding in Section 7.

[4] Articles like *There's Officially Too Much Netflix. What Happens Next?* [TIME, 2018], *Netflix Originals Are More Mediocre Than Ever* [Vice, 2019] are common.

[5] In Appendix A.9 we compare viewer ratings of Netflix and HBO shows and find that Netflix shows have a higher variance in audience ratings, especially lower rated shows compared to HBO.

[6] For example, The Crown, Stranger Things and The Man In the High Castle are all serials produced at a cost of $10 million or above an episode, only rarely matched by TV shows (latter seasons of hugely popular shows) [ScreenRant, 2020a], [ScreenRant, 2020b]. Also, in 2018 and 2020, Netflix was the most nominated platform (producer) at the Emmy Awards [Atlantic, 2018].

[7] It is worth noting that while better targeting ability of VOD services can explain an offering of higher quality programs or more niche programs, it is unlikely to explain the quality variation in contents with *prima facie* symmetric demand.

2 Related Literature

There is a healthy tradition of analytic inquiry into the economics of TV broadcasting. The themes that have received attention include bias against minority taste programs [Spence and Owen, 1977], welfare comparison — under market and monopoly provision [Anderson and Coate, 2005], quality provision under advertisement and pay-TV [Peitz and Valletti, 2008] and the two sided nature of TV broadcasting [Gal-Or and Dukes, 2003, Godes et al., 2009]. Our model starts where all these papers start — that the viewers are different in their taste for genres (content preference) and gain less utility from watching a program different from their preferred genre. With a focus on studying "on-demand" service, we model a setting where a program can be consumed in two periods, unlike in the papers analyzing traditional TV economics where time was not a dimension of interest and hence not explicitly modeled. The extension to multiple periods should be of value beyond this paper to analyze a richer set of questions on VOD services.

In the classical vertical product differentiation models like Shaked and Sutton [1982] quantity and quality are independent choices. In illustrating the changes with on-demand provision, we actively consider quantity-quality trade-offs, contributing in a small way to the literature [McCannon, 2008] that documents quantity-quality trade-offs in a firm's decision making. While we do not highlight variety in the paper, variety is an outcome of interest when viewers have preferences over different genres. Our setting allows pursuing questions on variety and quality-variety trade-offs (a question of theoretical interest Bohlmann et al. [2002]) and recent empirical interest in the digital media literature [Rao and Hartmann, 2015].

There is also an emerging literature in the digital media space that focuses on changes in production and consumption of programming due to technology changes. Smith and Telang [2016] considers at length how digitization changes production and consumption of programming. However their primary focus is the changes arising from the ability to harvest data and the gains that comes with this ability. We focus on the titular change associated with online provision of programming, its ”on-demand” nature. Belo et al. [forthcoming] and Godinho de Matos and Ferreira [2018] study experiments where a treatment group of households were accorded the viewer flexibility of a VOD service; (i) time shift TV[8] and (ii) binge watching. The papers study differences in viewer behavior compared to traditional TV, but not how it affects the service's decision on what programs to offer.

The analytical objective of our paper is closest to Taylor [2018]; a paper that analyzes how delay sensitivity among users affects price setting by on-demand service platforms compared to scheduled service platforms. Our aim is also to illustrate the changes in the service's decisions (in the changed, on-demand, setting) and the economic forces causing them. However, it is important to note that, unlike the on-demand platforms considered in Taylor [2018] (for services like food delivery and ride hailing), a VOD service's offering is unaffected by the time of day. Further, our focus is on quality and variety while Taylor [2018]'s is on price. Jiang et al. [2019] extends the Hotelling framework to study competition (of VOD services) under multi-homing. While they kick-start the literature on content decisions of VOD services, our focus (to illustrate the effects of "on-demand" provision) and modeling concerns are different (in fact, complementary); Jiang et al. [2019] concerns with 'why do VOD services have exclusive programming?' whereas the question of interest here is 'why do VOD services offer more programs and possibly higher quality?'.

3 Model

3.1 Preliminaries

A monopolist service provider aims to provide programming in two time slots (periods), t_1 and t_2. The viewership comprise a unit mass who are heterogeneous in their preferred time to watch a program (time preference), i.e., they prefer watching a program in one of

[8]Is a service that records programs broadcast, to make it available at a viewer's time of choosing.

the periods to the other, i.e., $t_1 \succ t_2$ or $t_2 \succ t_1$. Let half the viewers prefer t_1 to t_2 and the other half t_2 to t_1. This captures the heterogeneity in viewer time preferences; half the viewers preferring one period over the other corresponds to a viewership maximally different in their preferred time (an assumption we relax later in Section 6). A viewer's time preference is modeled in the following manner. In their preferred time, a viewer gets a utility ω from their outside option; in their less-preferred time, the utility they get from the outside option is higher: $(1 + \delta)\omega$, where $\delta > 0$. This captures the idea that viewers' demand for programming is not evenly distributed through the day/week. A high δ thus indicates a lower likelihood of watching a program in their less-preferred time (compared to the preferred time). $\omega \sim U[0, 1]$, which captures the idea that viewers are heterogeneous in their keenness to watch programs, creates the incentive for the service to improve the quality of programs.

A program could belong to one of two different genres, which we denote as A and B. The genres can be thought of as say, drama and comedy, or documentary and talk show. A viewer's utility from watching a program depends on two factors: (i) the quality at which the program is produced and (ii) whether the the genre matches with their taste. Let q_i denote the quality of an i-type program, where $i \in \{A, B\}$. We assume half the viewers prefer A to B ($A \succ B$) and the other half B to A, i.e., the viewers are also heterogeneous in their preferred genre. An i-preferring viewer gets a higher utility from watching an i-type program than a j-type program when either program is produced at the same quality ($q_i = q_j$) and $i \neq j \in \{A, B\}$. Let U_i^j denote the (gross) utility an i-preferring viewer gets when watching a j-type program, it is modelled as:

$$U_i^j = \begin{cases} q_j & \text{if } i = j \\ (1 - \lambda)q_j & \text{if } i \neq j, \text{ where } \lambda \in (0, 1). \end{cases} \tag{1}$$

For example, an i-preferring viewer gets a diminished utility $(1 - \lambda)q_j$ from watching

$A \succ B$ $t_1 \succ t_2$	$B \succ A$ $t_1 \succ t_2$
$A \succ B$ $t_2 \succ t_1$	$B \succ A$ $t_2 \succ t_1$

Figure 1: Distribution of viewer preferences

a program of genre j and quality q_j. The scenario where the viewers have a strong preference for genre (taste sensitivity) is captured by a high λ, whereas a low value of λ depicts the scenario where the viewers lose less from watching a program of a different genre from their preferred genre.

The viewers' time and genre preferences are independent. As a viewer is equally likely to prefer t_1 to t_2 (and vice versa) and equally likely to be A- or B-preferring, it follows that they are equally likely to be one of the four types shown in Figure 1. We make the following additional simplifying assumptions — (i) the viewers are not variety-seeking (watching a second program of the same genre by itself does not result in a diminished utility) and (ii) they get zero utility from repeat watching a program. We can now express the condition under which an i-type viewer watches a j-type program (their participation constraint) $U_j^i > \omega$, if it is their preferred time and $U_j^i > (1+\delta)\omega$, if it is their less-preferred time. We now need to distinguish how the viewers behave facing a linear TV service compared to a VOD service. Towards that we first describe the supply side.

3.2 Quality, Revenue and Program Offering

The monopolist service earns revenue from advertising during programming. All advertisers pay the service a per viewer fee, α, for some fixed level of advertising during a program, a level that is common to all the programs offered. This captures the idea that the revenue to the service from a program is proportional to its viewership. The revenue realized (from a program) can be expressed as $R = \alpha D$, where D is the viewership (demand) realized by that program. To simplify the analysis, we assume $\alpha = 1$, which means the revenue from a program is only equal to D, the viewership realized by it. Because the viewers are heterogeneous in their utility from the outside option, a higher quality program would result in more viewers watching, creating an incentive for the service provider to invest in a program's quality.

The monopolist service incurs a one-time cost in producing a program, which is linked to its quality. Let the cost incurred equal to cq^2, where q is the quality of the program. Let $c = \frac{1}{2}$, without any loss of generality. While there is no cost to serve an additional viewer once a program is produced, note that the service incurs a cost in gaining viewership through its investment in quality.

We have specified the revenue generated given the viewership of a program and the cost of producing a program. The viewership and consequently the revenue and profit generated by the service, depends on the menu of programs offered by the service — its program offering. An offering can be thought of as a list of programs (of A- or B-type) that the service chooses to produce and make available to the viewers. Let $\mathbf{S}$ denote the set of all possible program offerings of the service and S_i (a program offering) the i^{th} element of $\mathbf{S}$. Each offering has an associated list denoted as $\mathbf{q}_{S_i}$, comprising the quality levels of its constituent programs, i.e., the quality levels that maximize profit from the offering. Let $q_{S_i,p}$ denote the p^{th} element of the list $\mathbf{q}_{S_i}$, i.e., the quality of the p^{th} program in S_i. We can now look at the optimization problem of a service.

3.3 Sequence of Events

The following is the sequence of events:

- **Stage 1** The service chooses a program offering $S_i \in \mathbf{S}$, comprising one or more programs.

- **Stage 2** The service sets $\mathbf{q}_{S_i^*}$ the quality levels of the programs that constitute offering S_i.

- **Stage 3** The viewers make their choices of which programs to watch in t_1 and t_2 and the demand is realized.

We can solve the service provider's problem of choosing an offering and setting the quality of its constituent programs by backward induction. For any given program $p \in S_i$, let $D_{S_i,p}(\mathbf{q}_{S_i})$ denote the viewership realized by that program.

- We first express the profit realized from a program $p \in S_i$. We know the revenue from a program as equal to its viewership and the cost incurred in producing it as $\frac{q_{S_i,p}^2}{2}$. Therefore, the profit is

$$\pi_{S_i,p} = D_{S_i,p}(\mathbf{q}_{S_i}) - \frac{q_{S_i,p}^2}{2}. \tag{2}$$

- The profit realized by the service from the offering S_i can be expressed as the sum of profits from the constituent programs.

$$\Pi_{S_i} = \sum_{p \in S_i} \pi_{S_i,p}. \tag{3}$$

- The quality of the programs constituting the offering $\mathbf{q}_{S_i}$ is obtained as

$$\arg\max_{\mathbf{q}_{S_i}} \Pi_{S_i}. \tag{4}$$

- The service chooses the offering $S_i^* \in \mathbf{S}$ which gives them the highest profit $\Pi_{S_i^*}$ or Π^*.

$$\Pi_{S_i^*} = \max\{\Pi_{S_i} | S_i \in \mathbf{S}\}. \tag{5}$$

Clarity on two things should help us proceed along the steps outlined above. The first involves solving for the profit maximizing quality levels for the different programs that comprise an offering (Equation (4)). The other is to list the different offerings that a service would consider (elements of $\mathbf{S}$ in Equation (5)). Before we take up either of these, we formalize the key differences between a linear TV service and a VOD service as the offerings of either service are different.

3.4 Linear TV and VOD

The linear TV service is modeled as a single channel which shows programming in t_1 and t_2, i.e., at any given time it makes only one program available to the viewers. We can see that the TV channel's offering will either be a single program (which is repeated in t_2) or two programs — one of which is available in t_1 the other in t_2. With a VOD service, all programs on offer are available at both times (t_1 and t_2). Note that if opening TV channels was costless, the linear TV service can become a VOD service (i.e., open enough channels to make programs available at all times). However, this is not the case and technology of the traditional TV service limits it from providing "on-demand" service. However, they are still constrained and cannot offer all their programs at all times. Modeling a single channel curtails the TV service's ability to offer its programs at both times — allowing us to capture the key difference (between linear TV and VOD) of interest to this paper. We modify the notation to distinguish between the two types of services — TV channel and VOD, which is summarized in Table 1 below.

Given an offering (a list of programs and their quality levels), we need to express the viewership realized by constituent programs for either service. Note that any constituent program's viewership comprises viewers watching it in their preferred time and others watching it in their less-preferred time. If U^p denote the utility gained by a viewer from watching program p, recall (from Section 3.1) that the participation constraint for either service is the same; $U^p > \omega$ (in preferred time) and $U^p > (1 + \delta)\omega$ (in less-preferred

Table 1: Notation Guide; TV - VOD

TV	VOD	Description
TV	**V**	Set of program offerings
TV_i	V_i	i^{th} Program Offering
$q_{TV_i,p}$	$q_{V_i,p}$	Quality of the p^{th} program in TV_i/V_i
$D_{TV_i,p}$	$D_{V_i,p}$	Viewership of the p^{th} program in TV_i/V_i

time), respectively. The question that follows is which program would a viewer choose to watch in their preferred period and which one in their less-preferred period (incentive compatibility).

TV Channel: With the TV channel, as only one program is available at a time there is no incentive compatibility problem to resolve. If the channel offers only a single program; which is available in both t_1 and t_2, then a viewer considers watching the program in their preferred time. This follows from the preliminaries- watch it at a time when the outside option is less valuable: $U^p - \omega$ (net utility in the preferred time) $> U^p - (1 + \delta)\omega$ (net utility in the less-preferred time).

VOD: In the case of the VOD service, the viewers face the choice of which program to watch in their preferred time. Among the programs offered, a viewer only considers watching the two programs from which they get the highest utility. So now the question is would they watch the program that give them the highest utility in their preferred time or less-preferred time. The viewer would choose the former option — watch the highest utility giving program in their preferred time. The intuition is that if a viewer is likely to watch only one program, they would rather watch the one that gives them the highest utility and watch it at the time when their outside option is lower. We state a viewer's strategy in choosing which programs to watch and when as Lemma 1 below and its proof in Appendix A.1.

Lemma 1 *For a viewer, watching a program that gives them the highest utility in their preferred time weakly dominates the alternative of watching a program that gives the second highest utility in the preferred time.*

Now, given a list of programs (an offering) and their qualities, we can resolve how viewers would consider watching them. In other words, for a given offering (and the qualities of programs that constitute it), we can express the viewership (revenue) realized by each of the programs, for both the TV channel and the VOD service. With the revenue from each of the programs, we can solve for the respective qualities and the profits realized. To characterize the offerings of either service what is remaining is to enumerate their (respective) offerings (elements of sets $\mathbf{TV}$ and $\mathbf{V}$). Before we proceed, note the following point on how the viewership of a program is affected in different ways in either service. With a VOD service, a viewer's likelihood of watching a program p is not dependent on whether their preferred time is t_1 or t_2, which is indeed the case if the program is offered by a TV channel. However, when the VOD service is offering p, the type and quality of the other programs offered along with it affect a viewer's likelihood of watching p. Whereas, the program offered by a TV channel at the other time does not impact the likelihood of a viewer watching p.

4 Analysis

In subsection 4.1, we list the elements of the set $\mathbf{TV}$ — the set of possible offerings by the TV channel and then obtain expressions for the qualities (of the constituent programs) and profits from them. In subsection 4.2, we list the possible offerings of the VOD service and similarly obtain expressions for the quality and profits realized from each offering.

4.1 TV Offerings: Demand, Quality and Profits

The TV channel's offerings (the elements of set **TV**) comprise either a single program (which is then shown in both t_1 and t_2) or two programs. Let an A-type (B-type) program be denoted as A (B) and a second A-type (B-type) program be denoted as A' (B'). The different possible offerings of the TV channel are the following — $\{A, B, (A, B), (A, A'), (B, B')\}$. Here A and B are offerings comprising a single program and the others are offerings comprising two programs. As the genre preferences are symmetric, the service is indifferent between offering A and B when it offers a single program. When offering two programs, suppose A is offered in t_1. Now, in t_2, there are equal proportions of A- and B-preferring viewers[9]. Hence, the service is indifferent between offering B and A' in t_2. Therefore, more generally, the service is indifferent between the offerings — $(A, B) \sim (A, A') \sim (B, B')$.

We are interested in when does the channel offer a single program and when does it offer two programs; and what are the program qualities in either case. We assume the channel offers either (i) program A alone, denoted as TV_1, or (ii) programs (A, B), denoted as TV_2.

4.1.1 Offering: TV_1 - Program A in t_1, t_2

As a first step, we express the viewership realized by the program $D_{TV_1,A}$ as a function of its quality $q_{TV_1,A}$ and the two parameters δ and λ. As the same program is available in both periods, from Lemma 1 we know that viewers would watch the program in their respective preferred times. The participation constraint of the A-preferring viewers is $U_A^A = q_{TV_1,A} > \omega$; as $\omega \sim U[0, 1]$ the fraction of A-preferring viewers satisfying the constraint is $q_{TV_1,A}$. As half of the unit mass of viewers are A-preferring, the viewership realized from A-preferring viewers is $\frac{q_{TV_1,A}}{2}$. For B-preferring viewers the participation constraint is $U_A^B = (1 - \lambda)q_{TV_1,A} > \omega$. The viewership realized from B-preferring viewers

[9]We had previously noted how in the case of the TV channel viewership of a program is unaffected by the quality or type of the second program.

is $\frac{(1-\lambda)q_{TV_1,A}}{2}$. The total viewership of the offering (program) can be expressed as:

$$D_{TV_1,A} = \frac{q_{TV_1,A}}{2} + \frac{(1-\lambda)q_{TV_1,A}}{2}. \quad (6)$$

Quality and Profits:

As the offering comprises a single program, the associated quality list $\mathbf{q}_{TV_1}$ has one element, the quality of the program $q^*_{TV_1,A}$. We express the profit equation for this program as $\pi_{TV_1,A} = D_{TV_1,A} - \frac{q^2_{TV_1,A}}{2}$. $q^*_{TV_1,A}$, the profit maximizing quality $= \frac{(2-\lambda)}{2}$. We obtain the profit of the TV channel from the offering by substituting the quality expression in the profit equation as $\Pi_{TV_1} = \frac{(2-\lambda)^2}{8}$.

4.1.2 Offering: TV_2 - Program A in t_1, Program B in t_2

We first express the viewership realized by program A. One half of the A-preferring viewers and one half of B-preferring viewers have program A available in their preferred time. The fraction among them who watch the program satisfy the following participation constraints, $U^A_A = q_{TV_2,A} > \omega$ and $U^A_B = (1-\lambda)q_{TV_2,A} > \omega$. The viewership realized from these viewers, watching in their preferred time (t_1 here), is $\frac{q_{TV_2,A}}{4} + \frac{(1-\lambda)q_{TV_2,A}}{4}$. Similarly, for the other one half of A- and B-preferring viewers, t_1 is their less-preferred time and viewers who watch satisfy the following participation constraint $U^A_A = q_{TV_2,A} > (1+\delta)\omega$ and $U^A_B = (1-\lambda)q_{TV_2,A} > (1+\delta)\omega$. The viewership realized from among A-preferring and B-preferring viewers (watching in their less-preferred time) is $\frac{q_{TV_2,A}}{4(1+\delta)} + \frac{(1-\lambda)q_{TV_2,A}}{4(1+\delta)}$. The total viewership realized by the program is the sum of viewers for whom t_1 is a preferred time and t_2 is a preferred time.

$$D_{TV_2,A} = \frac{q_{TV_2,A}}{4} + \frac{(1-\lambda)q_{TV_2,A}}{4} + \frac{q_{TV_2,A}}{4(1+\delta)} + \frac{(1-\lambda)q_{TV_2,A}}{4(1+\delta)}. \quad (7)$$

From the symmetry in viewer preferences over taste for a genres and time (for watching programs) we can express the demand realized by program B in t_2 similarly as that of A:

$$D_{TV_2,B} = \frac{q_{TV_2,B}}{4} + \frac{(1-\lambda)q_{TV_2,B}}{4} + \frac{q_{TV_2,B}}{4(1+\delta)} + \frac{(1-\lambda)q_{TV_2,B}}{4(1+\delta)}. \quad (8)$$

Quality and Profits:

$\mathbf{q}_{TV_2}$, the associated list of program quality, comprises two entries. Again, from the symmetry we know both the programs would be set to the same quality (and realize identical profits to the channel). We can express the profit realized by the programs as $\pi_{TV_2,A} = D_{TV_2,A} - \frac{q^2_{TV_2,A}}{2}$ and $\pi_{TV_2,B} = D_{TV_2,B} - \frac{q^2_{TV_2,B}}{2}$, respectively. The qualities ($q^*_{TV_2,A}$ and $q^*_{TV_2,B}$) are obtained as the values that maximize the respective profits and is equal to $\frac{(2+\delta)(2-\lambda)}{4(1+\delta)}$. The profits from the programs are $\pi_{TV_2,A} = \pi_{TV_2,B} = \frac{(2+\delta)^2(2-\lambda)^2}{32(1+\delta)^2}$. We now have expressions for the program qualities and profit realized for either of the TV channel's offering in terms of the two parameters δ and λ. Table 2 presents the expressions for quick reference. Note that, in the single-program case, the quality and profits decrease with λ (genre preference) but are independent of δ (time preference), as the same program is shown in both the periods. Whereas, in the two-program case, they decrease with both λ and δ because (i) each program is watched by viewers of both the genres and (ii) the period in which it is shown is some viewers' preferred period while others' less-preferred period.

Table 2: TV Offerings - Quality and Profits

Offering (TV_i)	Quality ($q^*_{TV_i,p}$)	Profit ($\pi_{TV_i,p}$)	Total Profit ($\sum_{p\in TV_i} \pi_{TV_i,p}$)
TV_1	$q^*_{TV_1,A} = \frac{(2-\lambda)}{2}$	$\pi_{TV_1,A} = \frac{(2-\lambda)^2}{8}$	$\Pi_{TV_1} = \frac{(2-\lambda)^2}{8}$
TV_2	$q^*_{TV_2,A} = \frac{(2+\delta)(2-\lambda)}{4(1+\delta)}$	$\pi_{TV_2,A} = \frac{(2+\delta)^2(2-\lambda)^2}{32(1+\delta)^2}$	
	$q^*_{TV_2,B} = \frac{(2+\delta)(2-\lambda)}{4(1+\delta)}$	$\pi_{TV_2,B} = \frac{(2+\delta)^2(2-\lambda)^2}{32(1+\delta)^2}$	$\Pi_{TV_2} = \frac{(2+\delta)^2(2-\lambda)^2}{16(1+\delta)^2}$

4.2 VOD Offerings: Demand, Quality and Profits

For the VOD service, an offering is a collection of programs where any of the constituent programs is available to be watched in both t_1 and t_2. Note that the service is also not limited to offering a maximum of two programs. First, we list the possible offerings by the VOD service, i.e., the elements of $\mathbf{V}$. The maximum number of programs that the service can offer is four- two each of A-type and B-type. Any more program of either type is redundant as there is no third period to watch. We denote this offering as $V_4 = (A, A', B, B')$, where A' and B' are second programs of A- and B-type, respectively. The viewership may offer three programs. We denote such an offering as V_3. Let $V_3 = (A, A', B)$, i.e., two A-type programs and one B-type program[10]. Now consider an offering comprising two programs, $V_2 = (A, B)$[11]. The service could also choose to offer a single program. Let this offering be denoted as $V_1 = A$. So the set of VOD program offerings $\mathbf{V} = \{V_1, V_2, V_3, V_4\} = \{A, (A, B), (A, A', B), (A, A', B, B')\}$. We now proceed to express the demand realized by the programs in different offerings and solve for the qualities that maximize the profits from each offering.

Quality Decision of a VOD service

In the case of the TV channel, the quality decisions of a program offered say in t_1 did not affect the demand in t_2. In the case of the VOD service, the quality levels of the constituent programs determine how viewers make their decisions. In other words, the quality decision does not merely influence how many viewers watch, but also which programs they choose to watch in their preferred time and less-preferred time. For example, if the service offers programs A and B and chooses to set the quality of program A to a much higher level than that of program B, then the B-type viewers may get a higher utility

[10]The profits to the service and the net benefit to the viewers is identical if the three program offering instead had two B-type programs - (A, B, B').

[11]A two-program offering could also comprise (i) two A-type programs (A, A') or (ii) two B-type programs (B, B'). Offering (A, B) weakly dominates offerings constituting two programs of the same type. Intuitively, there is no advantage in catering to the viewers of only one genre, when the viewership comprises both A- and B-preferring viewers equally.

from watching program A, both types of viewers would consider watching program A in their preferred time despite having different tastes. However, if the difference in qualities is not too large (A and B have similar qualities), then A-type viewers would get a higher utility from program A and B-type from program B and would respectively choose program A and program B to watch in their preferred time. So when choosing $\mathbf{q}_{V_i}$ (the qualities of constituent programs), the service also chooses how viewers rank the constituent programs in terms of the utility they get from each of them.

4.2.1 Offering: V_1 - Program A

We can see that from the perspective of the viewers, offering only one program (V_1) is identical to the offering TV_1- program A available in both t_1 and t_2. So $\mathbf{q}_{TV_1} = \mathbf{q}_{V_1}$ and $\Pi_{TV_1} = \Pi_{V_1}$ whose expressions we have already derived in section 4.1.1.

4.2.2 Offering: V_2 - Programs (A, B)

When there are two programs on offer, we know from Lemma 1 that viewers in their preferred time choose to watch that program which gives them the highest utility. If $(1-\lambda)q_{V_2,A} > q_{V_2,B}$ then A is the program that gives both A- and B-preferring viewers the higher utility among the two programs ($U_A^A > U_A^B$ and $U_B^A > U_B^B$). Whereas, if the quality of one of the two programs is not much higher than the other— $(1-\lambda)q_A < q_B$ and $(1-\lambda)q_B < q_A$, A-preferring viewers would have A as their preferred-time choice and B-preferring viewers would have B as their preferred-time choice ($U_A^A > U_A^B$ and $U_B^B > U_B^A$). The demand and the profits realized by the programs in either case would be different. So, we first resolve how the VOD service sets the qualities when offering two programs. We denote the case where either type of viewers choose a program aligned to their respective tastes as V_{2s} and the case where one of the programs is set to a higher quality and becomes the preferred program for both types of viewers as V_{2a}.

Case i: V_{2s}

We present the expressions for viewership when the two programs offered are such that the A-preferring viewers consider to watch A and B-preferring viewers consider to watch B in their respective preferred times. In their less-preferred time, they consider (watching) the program not aligned with their taste. Here, the viewership of a program comprises viewers watching it in their preferred time and those watching it in their less-preferred time. The viewership of A ($D_{V_{2s},A}$) comprise A-preferring viewers who satisfy — $U_A^A > \omega$ and B-preferring viewers who satisfy — $U_B^A > (1+\delta)\omega$, which respectively are $\frac{q_{V_{2s},A}}{2}$ and $\frac{(1-\lambda)q_{V_{2s},A}}{2(1+\delta)}$. We can express the viewership realized by program B ($D_{V_{2s},B}$) as following.

$$D_{V_{2s},A} = \frac{q_{V_{2s},A}}{2} + \frac{(1-\lambda)q_{V_{2s},A}}{2(1+\delta)}. \tag{9}$$

$$D_{V_{2s},B} = \frac{q_{V_{2s},B}}{2} + \frac{(1-\lambda)q_{V_{2s},B}}{2(1+\delta)}. \tag{10}$$

Case ii: V_{2a}

When $U_B^A = (1-\lambda)q_{V_{2a},A} > U_B^B = q_{V_{2b},B}$, both A- and B-preferring viewers watch program A in their preferred time. Their respective participation constraints are $U_A^A > \omega$ and $U_B^A > \omega$. The viewership realized comprises $\frac{q_{V_{2a},A}}{2}$ of A-preferring and $\frac{(1-\lambda)q_{V_{2a},A}}{2}$ of B-preferring viewers. In their less-preferred time, both A- and B-preferring viewers would consider watching B. Their respective participation constraints are $U_A^B > (1+\delta)\omega$ and $U_B^B > (1+\delta)\omega$. The viewership realized comprises $\frac{q_{V_{2a},B}}{2(1+\delta)}$ of A-preferring and $\frac{(1-\lambda)q_{V_{2a},B}}{2(1+\delta)}$ of B-preferring viewers.

$$D_{V_{2a},A} = \frac{q_{V_{2a},A}}{2} + \frac{(1-\lambda)q_{V_{2a},A}}{2}. \tag{11}$$

$$D_{V_{2a},B} = \frac{q_{V_{2a},B}}{2(1+\delta)} + \frac{(1-\lambda)q_{V_{2a},B}}{2(1+\delta)}. \tag{12}$$

Table 3: VOD Two Program Offering: Quality and Profit

Offering	Quality	Profit	Total Profit
V_{2s}	$q^*_{V_{2s},A} = \frac{(2+\delta-\lambda)}{2(1+\delta)}$	$\pi_{V_{2s},A} = \frac{(2+\delta-\lambda)^2}{8(1+\delta)^2}$	
	$q^*_{V_{2s},B} = \frac{(2+\delta-\lambda)}{2(1+\delta)}$	$\pi_{V_{2s},B} = \frac{(2+\delta-\lambda)^2}{8(1+\delta)^2}$	$\Pi_{V_{2s}} = \frac{(2+\delta-\lambda)^2}{4(1+\delta)^2}$
V_{2a}	$q^*_{V_{2a},A} = \frac{(2-\lambda)}{2}$	$\pi_{V_{2a},A} = \frac{(2-\lambda)^2}{8}$	
	$q^*_{V_{2a},B} = \frac{(2-\lambda)}{2(1+\delta)}$	$\pi_{V_{2a},B} = \frac{(2-\lambda)^2}{8(1+\delta)^2}$	$\Pi_{V_{2a}} = \frac{(2-\lambda)^2(2+\delta^2+2\delta)}{8(1+\delta)^2}$

Quality and Profits:

With the demand specified, we obtain the qualities and profits to the service when offering two programs for both cases i and ii. We compare them to learn the optimal quality choice for a VOD service while offering two programs. We obtain the respective qualities and profits for either case — $(\mathbf{q}_{V_{2s}}, \Pi_{V_{2s}})$ and $(\mathbf{q}_{V_{2a}}, \Pi_{V_{2a}})$, respectively. The expressions obtained are presented in Table 3. In Case i the two programs are set to the same (symmetric) quality level and in Case ii to different (asymmetric) qualities. Note that the higher quality in the asymmetric-qualities case is the same as the quality set by linear TV in the single-program case, which is independent of δ. This is because in both the scenarios the program is watched by all the viewers (both A- and B-preferring) in their preferred period. We compare the expressions for $\Pi_{V_{2a}}$ and $\Pi_{V_{2s}}$ to learn how the service will set qualities when offering two programs.

Proposition 1 *When offering two programs (V_2), the VOD service sets the programs to asymmetric qualities ($\mathbf{q}_{V_{2a}}$) when the viewers have a weak genre preference $\left(\lambda < 2 - \sqrt{2}\right)$ but a relatively strong time preference $\left(\delta > \dfrac{4\lambda - 2\lambda^2}{2 - 4\lambda + \lambda^2}\right)$, and to symmetric qualities ($\mathbf{q}_{V_{2s}}$), otherwise.*

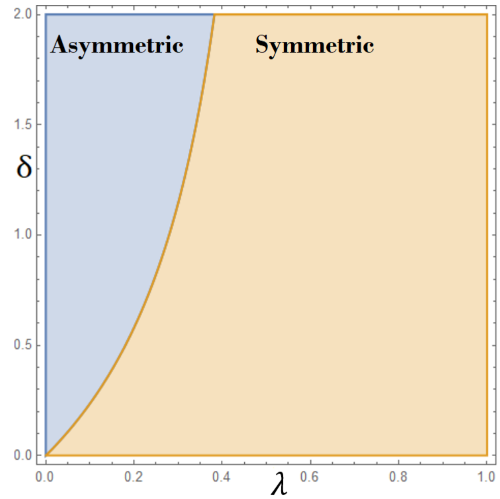

Figure 2: VOD service sets asymmetric qualities; offering- $V2a$ dominates offering $V2s$ when $\delta > \frac{4\lambda-2\lambda^2}{2-4\lambda+\lambda^2}$.

Proposition 1[12] conveys that, when the VOD service offers two programs, it has an incentive to produce them at asymmetric qualities when the viewers have a strong time preference (high δ) and a weak genre preference (low λ). In other words, they offer programs such that all the viewers have the same program as their preferred time choice, irrespective of their genre preference[13].

We know that at a high δ, viewers are less likely to watch a program in their less-preferred time, i.e., they have a relatively low demand for a second program. A service offering two programs in this scenario has the incentive to focus more on one program and get all viewers to choose this program for their preferred time. However, viewers have genre preferences and half viewers prefer one genre to the other. So, there is also a simultaneous incentive to cater to both tastes and symmetrically invest in two programs. When λ is high and viewers have relatively low demand for a program of a different genre, the service has the incentive to symmetrically invest in both programs. When λ is low, viewers have relatively low utility loss from taste mismatch. In other words the cost of

[12]The proof of the statement is presented in Appendix A.2.

[13]Note that Proposition 1 only conveys quality setting for the offering V_2, we have not yet resolved which offering (among V_1, V_2, V_3 and V_4) the service actually chooses, which is resolved in subsection 4.3.

providing half the viewers a program not of their preferred genre for their preferred time, is smaller. For example, in this scenario the service is better off focusing its investments on a drama (say) as opposed to a comedy even when half the viewers prefer comedy to drama (and vice versa). Comedy-preferring viewers also choose the (superior) drama for their preferred time. Therefore as Proposition 1 states, the service finds it optimal to offer two programs at asymmetric qualities when δ is high and λ is low.

When viewers' time preference (δ) is relatively low, they have a relatively higher demand for a second program too. As the service also has the incentive to cater to either tastes (symmetric genre preferences), it is optimal to offer one program of either genre (A and B) produced at the same quality—offering V_{2s}. A high λ reinforces this incentive, bringing all viewers to have the same program (albeit higher quality) as their preferred time choice is costly; viewers who prefer the other genre has relatively low demand for the high quality program in this scenario.

To complement the above intuition, we can inspect the demand realized in either cases. In the asymmetric case all viewers have the same program as their preferred time choice whereas in the symmetric case they have the program of their respective genre as the preferred time choice. We can write down the expressions for the viewership accruing from preferred time watching in either setting. When the service sets symmetric qualities, then we know (from Equation (9)) that program A gets a preferred-time viewership of $\frac{q^*_{V_{2s},A}}{2}$ and so does program B. By substituting the expression, the preferred-time viewership of the service can be expressed as $\frac{(2+\delta-\lambda)}{2(1+\delta)}$. We can express the preferred time viewership when offering asymmetric qualities by substituting $q_{V_{2a},A}$ in Equation (11) as $\frac{(2-\lambda)^2}{4}$. The difference between the two cases is $\left(\frac{(2-\lambda)^2}{4} - \frac{(2+\delta-\lambda)}{2(1+\delta)}\right)$. We should expect to see the expression increasing in δ and decreasing in λ. We can verify that the expression is indeed increasing in δ[14] and decreasing in λ[15].

[14]The partial derivative $\left(\frac{\partial(.)}{\partial\delta}\right)$ is $\frac{1-\lambda}{2(1+\delta)^2}$, which is positive for all $\delta > 0$ and $\lambda \in (0, 1)$.

[15]The partial derivative of the difference $\left(\frac{\partial(.)}{\partial\lambda}\right)$, is $\left(\frac{1}{2(1+\delta)} + \frac{(-2+\lambda)}{2}\right)$ which is negative for all $\delta > 0$ and

4.2.3 Offering: V_4 - Programs (A, A', B, B')

Before discussing the three-program offering V_3 we discuss the symmetric offering of four programs. First, we resolve how the service sets the qualities, before writing down the expressions for the viewership realized by each of the programs. The qualities are set such that, in any period, i-preferring viewers watch either i or i' for $i \in \{A, B\}$. This is because if i-preferring viewers watch j or j', where $i \neq j$, then there is no viewership for at least one of the i-type programs which essentially leads to an offering of less than four programs.

Programs i and i' for $i \in \{A, B\}$ can be offered at equal or different (asymmetric) qualities. Without any loss of generality, suppose that $q_{V_4,i} \geq q_{V_4,i'}$. Note that when offering two programs of either genre, the service is catering to viewers' demand for programs consistent with their genre preferences. Unlike when offering two programs, setting these programs to asymmetric qualities ($q_{V_4,i} > q_{V_4,i'}$) does not come at the cost of equally catering to genre preferences. As viewers have time preference and therefore less demand for watching a second program, the service has the incentive to focus its investments on one of the programs. Similar to when offering two programs (V_{2a}), when one of the programs is of a higher quality, all i-preferring viewers' choice for their preferred time is the higher quality i (and i' in their less preferred period).

We can verify that the service indeed offers four programs at asymmetric qualities, as follows. When program i is set to a higher quality $q_{V_4,i} > q_{V_4,i'}$, all i-preferring viewers consider watching the program in their preferred time. Viewer's participation constraint is that the utility from watching i is greater than the outside option ($U_i^i > \omega$). The viewership realized $D_{V_4,i} = \frac{q_{V_4,i}}{2}$. Viewers consider i' for the less-preferred time, the participation constraint is $U_i^{i'} > (1+\delta)\omega$ and the viewership realized $D_{V_4,i'} = \frac{q_{V_4,i'}}{2(1+\delta)}$, where $i \in \{A, B\}$.

Alternatively, if the service had set the programs to identical qualities ($q_{V_4,i} = q_{V_4,i'}$),

$\lambda \in (0, 1)$.

viewers choose with equal probability one of the programs for their preferred time and the other for the less preferred time. A viewer's participation constraint for watching in their preferred time is $U_i^i > \omega$ and in their less-preferred time $U_i^i > (1+\delta)\omega$. The viewership realized by program i in this case is $\frac{q_{V_4,i}}{4} + \frac{q_{V_4,i}}{4(1+\delta)}$, which is equal to the viewership realized by i'. Note that in either case the viewership realized for programs B and B' can be expressed by isomorphic expressions. We summarize the viewership realized by the programs in either cases in the Table below.

Table 4: Offering V_4 - Asymmetric Vs Symmetric Quality

Symmetric	Asymmetric
$q_{V_4,A} = q_{V_4,A'} = q_{V_4,B} = q_{V_4,B'}$	$q_{V_4,A} = q_{V_4,B} > q_{V_4,A'} = q_{V_4,B'}$
$D_{V_4,i} = \frac{q_{V_4,i}}{4} + \frac{q_{V_4,i}}{4(1+\delta)}$	$D_{V_4,i} = \frac{q_{V_4,i}}{2}$
$D_{V_4,i'} = \frac{q_{V_4,i'}}{4} + \frac{q_{V_4,i'}}{4(1+\delta)}$	$D_{V_4,i'} = \frac{q_{V_4,i'}}{2(1+\delta)}$

Without proceeding to solve for the profits realized in either case, we can resolve the quality setting problem by comparing it to Proposition 1. Note that $D_{V_4,i}$ equals $\frac{D_{V_{2s},i}}{2}$ or $\frac{D_{V_{2a},i}}{2}$ when $\lambda = 0$ (see Equations (9, 10) and (11, 12)). In other words, this problem (how the qualities of two A-type programs are set) is isomorphic to how the VOD service sets quality when offering two programs when $\lambda = 0$. From Proposition 1 we already know the service sets asymmetric qualities at $\lambda = 0$. Therefore, while offering four programs the VOD service sets A (B) to a higher quality than A' (B')[16]. We state this as a corollary to Proposition 1.

Corollary 1 *When offering more than one program of the same type, the VOD service sets them to asymmetric qualities, where the difference in the qualities is increasing in* δ*.*

With the quality setting question resolved, we can specify the viewership realized by A and A' (also B and B').

[16]See proof in Appendix A.3.

Table 5: VOD Four Program Offering: Quality and Profit

Offering	Quality ($q^*_{V_4,p}$)	Profit ($\pi_{V_4,p}$)	Total Profit ($\sum_{p\in V_4}\pi_{V_4,p}$)
V_4	$q^*_{V_4,A} = \frac{1}{2}$	$\pi_{V_4,A} = \frac{1}{8}$	
	$q^*_{V_4,A'} = \frac{1}{2(1+\delta)}$	$\pi_{V_4,A'} = \frac{1}{8(1+\delta)^2}$	
	$q^*_{V_4,B} = \frac{1}{2}$	$\pi_{V_4,B} = \frac{1}{8}$	
	$q^*_{V_4,B'} = \frac{1}{2(1+\delta)}$	$\pi_{V_4,B'} = \frac{1}{8(1+\delta)^2}$	$\Pi_{V_4} = \frac{2+\delta^2+2\delta}{4(1+\delta)^2}$

$$D_{V_4,A} = \frac{q_{V_4,A}}{2} \;\; ; \;\; D_{V_4,B} = \frac{q_{V_4,B}}{2}. \tag{13}$$

$$D_{V_4,A'} = \frac{q_{V_4,A'}}{2(1+\delta)} \;\; ; \;\; D_{V_4,B'} = \frac{q_{V_4,B'}}{2(1+\delta)}. \tag{14}$$

Quality and Profits:

With the viewership (demand) specified, we obtain expressions for quality of the constituent programs. We summarize the expressions for quality and profits realized when the VOD service offers four programs in Table 5. Note that the two programs A and B are offered at a higher quality compared to A' and B'. Further note that the higher quality is independent of both δ and γ, truly capturing the advantage of the on-demand service to provide a viewer a program of their preferred genre in their preferred time.

4.2.4 Offering: V_3 - Programs (A, A', B)

The three-program offering has two A-type programs and one B-type program[17]. When two A-type programs are offered, the A-preferring viewers only watch the A-type programs. If they were to instead watch B, then one of the A-types programs (say A') would

[17]Note that service can instead offer two B-type programs along with an A-type program; the profit realized and the viewer welfare would be identical to the case discussed here.

not have any viewership[18], which essentially leads to the two-program case, V_2, where only A and B are offered. When the service offers two A-type programs, we also know from previous discussions that one of them is offered at a higher quality (say $q_{V_3,A} > q_{V_3,A'}$).

It follows from Lemma 1 that the A-preferring viewers consider watching A in their preferred time and A' in their less-preferred time. The B-preferring viewers have (i) B as their preferred-time choice when $q_{V_3,B} > (1-\lambda)q_{V_3,A}$ and (ii) A as their preferred-time choice when $q_{V_3,B} < (1-\lambda)q_{V_3,A}$. Let the first case be denoted as V_{3i}. Here A is watched by both A- and B-preferring viewers (the latter in their less-preferred time), B is watched by B-preferring viewers (in their preferred time) and A' by A-preferring (in their less-preferred time). In the second case (V_{3ii}) A is the preferred-time choice for all the viewers. In their less-preferred time, A- and B-preferring viewers watch A' and B, respectively. Like in the preceding subsections, we express the viewership accrued in either case as Equations (15) and (16).

$$D_{V_{3i}} = \begin{cases} \frac{q_{V_{3i},A}}{2} + \frac{q_{V_{3i},A}(1-\lambda)}{2(1+\delta)} & \text{viewership of } A; \\ \frac{q_{V_{3i},A'}}{2(1+\delta)} & \text{viewership of } A'; \\ \frac{q_{V_{3i},B}}{2} & \text{viewership of } B. \end{cases} \tag{15}$$

$$D_{V_{3ii}} = \begin{cases} \frac{q_{V_{3ii},A}}{2} + \frac{q_{V_{3ii},A}(1-\lambda)}{2} & \text{viewership of } A; \\ \frac{q_{V_{3ii},A'}}{2(1+\delta)} & \text{viewership of } A'; \\ \frac{q_{V_{3ii},B}}{2(1+\delta)} & \text{viewership of } B. \end{cases} \tag{16}$$

We obtain the profit realized in both the cases as $\Pi_{V_{3i}} = \frac{1}{8} + \frac{1}{8(1+\delta)^2} + \frac{(2+\delta-\lambda)^2}{8(1+\delta)^2}$ and $\Pi_{V_{3ii}} = \frac{1}{4(1+\delta)^2} + \frac{(2-\lambda)^2}{8}$, respectively. Now that the expressions for the profits realized from all four program offerings have been obtained, we can proceed to characterize the optimal offerings of the VOD service. In the next subsection, we determine both for the TV channel

[18] If $U_A^B > U_A^{A'}$ then $U_B^B > U_B^{A'}$ and therefore program A' will have no viewership.

and VOD service the optimal offering, for a given level of δ and λ.

4.3 Optimal Offerings

We now compare the profit expressions of the different offerings obtained so far to determine the optimal offering of the two services. To recap, for the TV channel, the comparison is between offering a single program (TV_1) or two different programs (TV_2); for the VOD service, the comparison is among the four offerings (V_1, V_2, V_3 and V_4). Now that we have obtained the expressions for the profits realized in each of these cases, we find the optimal offering for any given δ and λ (Equation (5) in subsection 3.3).

4.3.1 TV service: Optimal Offerings

As there are just two linear TV offerings of interest, TV_1 and TV_2, we can simply compare Π_{TV_1} and Π_{TV_2} (see Table 2) to characterize the optimal TV offering. We report the result in Lemma 2 below.

Lemma 2 *When viewers have a strong time-preference ($\delta > \sqrt{2}$), the TV channel offers a single program (TV_1). Otherwise, it offers two programs (TV_2).*

In Figure 3 we illustrate Lemma 2[19]. We first discuss the case where the TV channel is offering two programs. We know in either periods t_1 and t_2, the demand for watching a program is the same, as there are as many viewers who like watching in t_1 to t_2 and vice versa. This is the incentive for the TV channel to offer two programs. We also know when $\delta > 0$, the viewers are not as keen on watching a second program. From the discussion of Proposition 1 we know, that this is an incentive for the service to invest more in one of the two programs. However, the benefit from asymmetric investment in programs is realized only when it is available always, so that all viewers can watch it their preferred time. The TV channel which can show only one program at a time, can achieve this only

[19]We present the algebraic verification of the statement in Appendix A.4

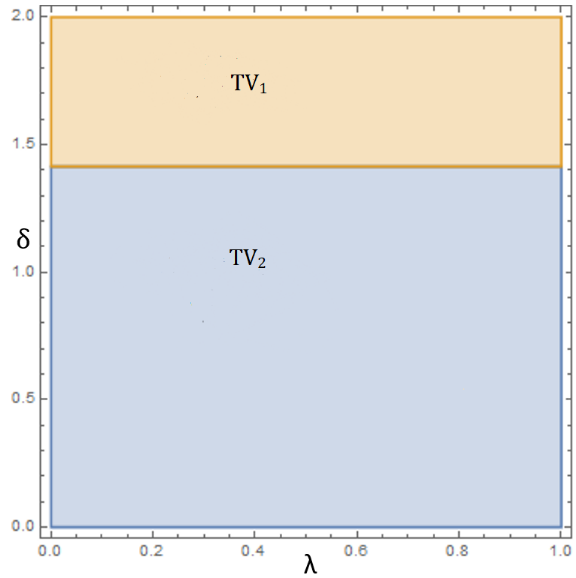

Figure 3: TV Channel - Program Offerings

by trading off the ability to show a second program. When δ is very high ($\delta > \sqrt{2}$) the TV channel does trade off the ability to offer two programs, to focus on one program which is then made available in both t_1 and t_2 and all the viewers can watch in their preferred time. At a lower δ, viewer time preference is not intense enough to trade-off for the gains from making a program available at the preferred time for either type of viewers.

4.3.2 VOD Service: Optimal Offerings

The VOD offerings of interest to us include V_1, V_2, V_3 and V_4. We have the expressions for qualities and profits realized by the different offerings from the previous subsection. We compare the profits of the candidate offerings for a given (δ, λ) to identify the offering that gives the highest profits for that set of parameter values. The result is reported as Lemma 3 below.

Lemma 3 *(a) The service chooses the two-program offering - set to asymmetric qualities (V_{2a}) when* $\lambda < 2 - \sqrt{2}$ *and* $\delta > \dfrac{4\lambda - 2\lambda^2}{2 - 4\lambda + \lambda^2}$.

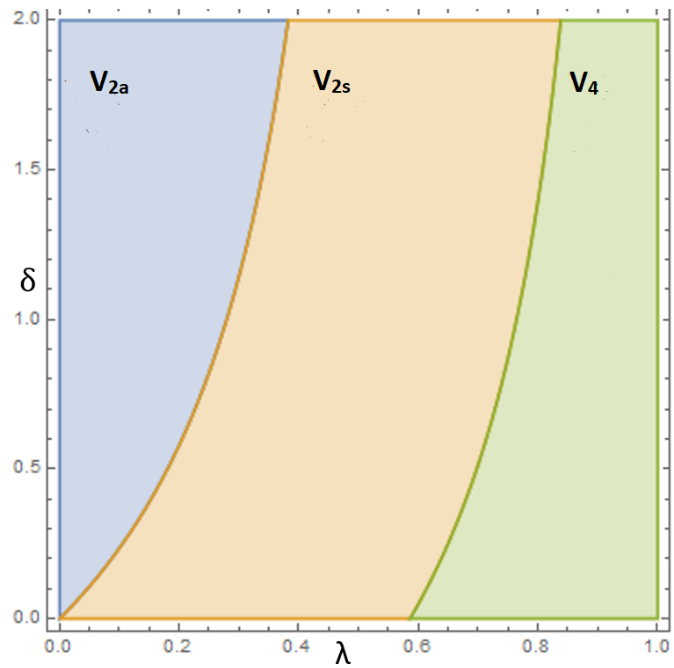

Figure 4: VOD service: Program Offerings

(b) The service chooses the two-program offering - set to symmetric qualities (V_{2s}) *when (i)* $0 < \lambda < (2-\sqrt{2})$ and $\delta < \dfrac{4\lambda - 2\lambda^2}{2 - 4\lambda + \lambda^2}$*; (ii)* $(2-\sqrt{2}) < \lambda < 1$ and $\delta > \dfrac{2 - 4\lambda + \lambda^2}{2\lambda - 2}$*; or (iii)* $\lambda = (2-\sqrt{2})$ and $\delta \in \mathbb{R}_+$.

(c) The service offers four programs (V_4) *when* $(2-\sqrt{2}) < \lambda < 1$ *and* $0 < \delta < \dfrac{2 - 4\lambda + \lambda^2}{2\lambda - 2}$.

We verify the statement of Lemma 3 in Appendix A.5. First note that the service does not offer either a single program (V_1) or three programs (V_3). This is intuitive as viewers are symmetrically distributed over two genres and service is catering to demand in two periods. For clarity, the optimal offerings of the VOD service (Lemma 3) is illustrated in Figure 4. The three offerings are shaded as different regions in the figure. In our discussion of Proposition 1, we have covered VOD's choice of offering two programs. So we focus here on when does the service offer four programs? When the service offers four programs, it allows viewers to watch a program consistent with their genre-taste in both their preferred and less-preferred periods. This suggests that the four-program offering is more likely the choice when the viewers get a high level of dis-utility from taste mismatch of the program (high λ). This also suggests that the service would offer the two additional programs when viewers are more likely to watch a second program, or that the marginal revenue from the viewers watching in their less-preferred time is higher (low δ). We can verify from the illustration (Figure 4) that the service chooses to offer four programs at a high λ and a relatively low δ.

Note that when offering four programs (more programs) the VOD service leverages its ability to make more programs available. We further know that the offering comprises two programs set to a higher quality (and the other two at a lower quality), due to the ability of the VOD service to make the programs available at both t_1 and t_2 (see discussion of Proposition 1). Now with this clarity on how the VOD service offers programs and sets qualities we can examine how the VOD offerings are different from those of a TV channel.

5 Comparing the Offerings of Linear TV and VOD Services

By now we know that either mode of service's offering is different and this difference varies depending on the level of viewer time preference and their disutility from taste mismatch. In comparing the program choices by either type of service we are interested in two aspects, when does the VOD service provide more programs and when does it provide higher quality. Before taking this up, we synthesize the insight conveyed through Proposition 1 and the discussion on TV channel's program decisions, the key difference between the program decisions of either type of service. When viewers' have time preference, their demand for watching programs varies through the day. A service has the incentive to make asymmetric investments in the programs it produces, as the returns to quality of a program watched in viewers' preferred period is higher. However, if viewers' preferred period is distributed in time, then the program should always be available (to viewers) to benefit from the strategy. The TV channel can do so only by losing the opportunity to show other programs which is not the case with the VOD service where the programs are available on-demand. In other words, we have illustrated the VOD service's incentive for asymmetric investments in program quality which the TV channel cannot adopt.

5.1 When does the VOD service offer more programs than the TV service?

We have just discussed how if the TV channel wants all viewers to watch a program in their preferred time, they have to make it available at all times, which comes at the cost of showing a second program, while the VOD service does not face this constraint. So, when facing a viewership with a strong time preference (high δ) the VOD service always offers more programs than the TV channel. We know, at a high δ the trade-off facing the TV channel is the viewership it can gain from offering a second program and the viewership it will lose from the inability to make this program available at both times (t_1 and t_2) which increases with δ. With the VOD service, as the program is available at all times this trade-off does not arise. It is indeed not uncommon to see repeat programming on TV channels, i.e., showing a program aired earlier. Our discussion makes the point that if the channel was doing so (trading off the opportunity to show a new program) for the ability to reach an audience who prefer watching it later, a VOD service coming in its place would offer more programs.

We now look at the case where the TV offers two programs (not trading-off the opportunity to show the program at all times) but the VOD service offers more (four) programs. From Lemmas 2 and 3, we know that this happens when the viewers have strong genre preferences. In this case, the VOD service caters finely to viewer tastes and produces two programs of either genre. The TV channel cannot mimic the VOD service, as it does not have the capacity to offer more programs. In the right-side image of Figure 5, we plot the

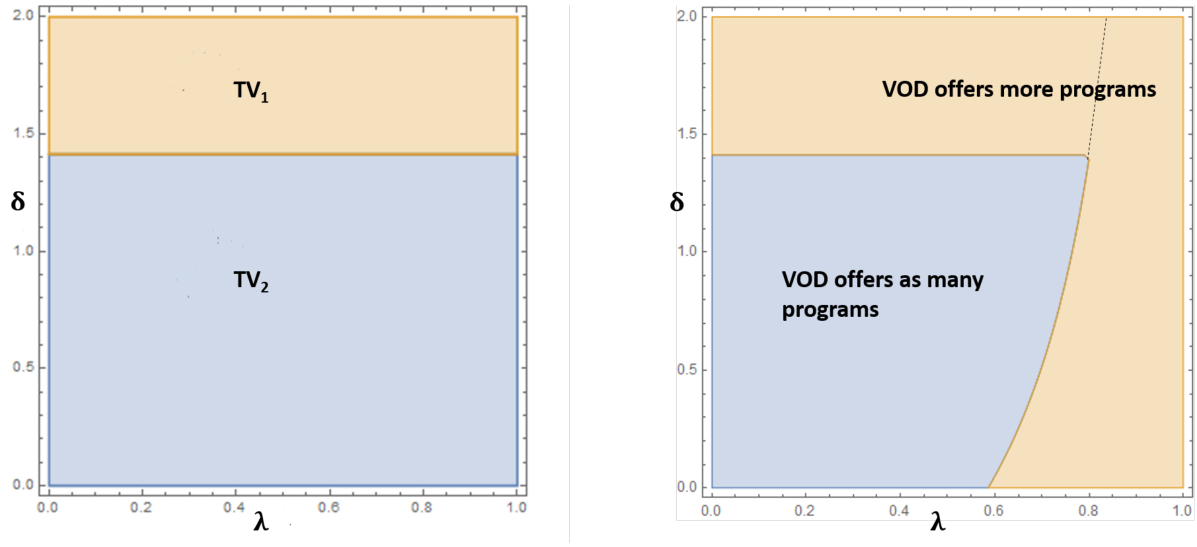

Figure 5: Comparing the Number of Programs Offered by TV and VOD

regions where the VOD offers equal or higher number of programs than the TV channel[20].

5.2 When does the VOD service provide higher quality?

Now that we have discussed the difference in the number of programs offered (variety), let us turn our attention to the differences (between TV and VOD) in the quality the respective programs offered are set to. When more programs are offered, the marginal (viewership) gain from the quality of a program is lower, as there are fewer viewers to gain now due to the cannibalization of demand by the other programs on offer. When the VOD service is offering more programs, the quality of programs is adversely affected by this aspect. However, the ability to show a chosen program to all the viewers in their preferred time means the marginal gain from quality can also be higher for such a program.

In our setting, when the TV channel offers a single program, it is offering fewer programs than the VOD service and also making it available in t_1 and t_2. The gain from increasing quality is the highest for this program. So, when $\delta > \sqrt{2}$ (where the TV channel

[20]It would seem that in this region the disadvantage of the TV channel comes from a simple capacity constraint, which is captured here as a restriction of the TV to a single channel. Note that if the TV adds capacity, apart from incurring the cost to do so, it also has to resolve whether the excess capacity is best utilized to make available the original programs in both t_1 and t_2 or show new programs.

offers a single program) the quality offered is at least as high as any program offered by the VOD service. The parameter range where this holds is represented as region I(a) in Figure 6.

We next consider the case where both the TV channel and the VOD service are offering two programs (see Figures 3 and 4). When both the services are offering the same number of programs, with the additional advantage of making the programs available in the preferred time to all the viewers, we should expect the VOD service to offer programs set to a higher quality. The exception is when VOD service makes asymmetric investments in two programs. The lower quality program among them is the less-preferred time choice for all the viewers. The programs on linear TV offered in t_1 and t_2 cater to both preferred time viewers and less preferred time viewers. Therefore the incentive to invest in the latter's quality is higher. We state these in Proposition 2 below.

Proposition 2 *When both the TV channel and the VOD service offer 2 programs -* (TV_2, V_{2s}) *and* (TV_2, V_{2a})*,*

(i) the higher (lower) quality program offered by the VOD service when it sets the programs to asymmetric qualities (TV_2, V_{2a}) *is of a higher (lower) quality than the programs offered by the TV channel* $\left(q^*_{V_{2a},A} > q^*_{TV_2,A} = q^*_{TV_2,B} > q^*_{V_{2a},B}\right)$*; and*

(ii) both the programs of the VOD service would be of a higher quality than offered by the TV channel when it sets the programs to symmetric qualities $\left(q^*_{V_{2s},A} = q^*_{V_{2s},B} > q^*_{TV_2,A} = q^*_{TV_2,B}\right)$.

We present the conditions for Proposition 2 as regions II and III, respectively, in Figure 6. In the first case here (region II in Figure 6), the VOD service makes asymmetric investments in programs as the cost of not equally catering to both genres is not high owing to viewers having a relatively small disutility when watching a program not of their preferred genre (low λ). It is relatively straightforward to reason how if a VOD service and a TV channel was offering the same number of programs that the former's

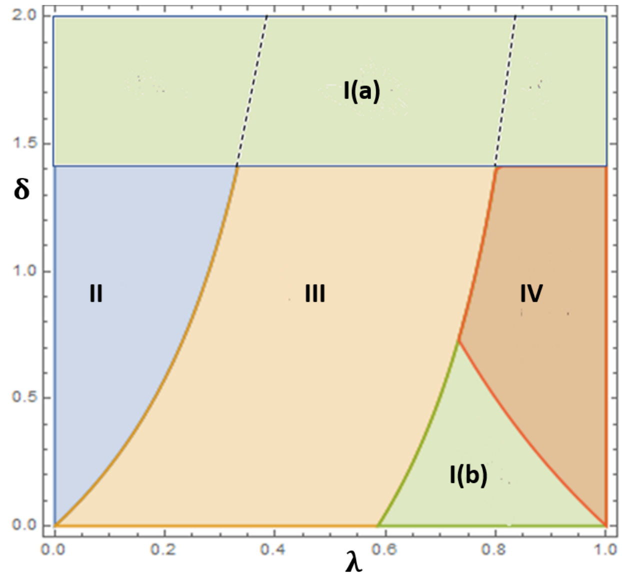

Figure 6: Comparing the Number of programs and Quality Offered by TV and VOD. Regions I(a) and I(b) represent the parameter ranges where the VOD offers more programs than the TV, but all the qualities are lower or equal. Region II represents the parameter ranges where both services offer two programs, but only one of the VOD programs is of a higher quality. Region III represents the parameter ranges where both services offer two programs, and the quality of both VOD programs is higher. Finally, region IV represents the parameter values where the VOD offers more programs than the TV, and at least as many programs of a higher quality.

offering could be superior. However without modeling on-demand consumption, it is not obvious why some (one here) of those programs could be of a lower quality.

In the second case the VOD service offers two programs set to symmetric (identical) qualities (region III in Figure 6). We know in this case, A- and B-preferring viewers watch programs of their respective genres in their preferred time. Whereas, with the TV, only those A-preferring (or B-preferring) viewers whose preferred time happens to be when the channel is showing A (or B) have the option of watching it in their preferred time. The ability to get all the interested viewers with the same taste to watch the program in their preferred time means a higher (marginal) gain from investing in quality, when offered by the VOD service.

VOD: More Programs and Higher Quality

Now we take up the quality question when the VOD service offers four programs but the TV service offers only two (see Figures 3 and 4). As discussed earlier, more choices of programs reduces the marginal gain from quality of the individual programs. However, we also know that the VOD service sets two among those programs to a high quality. So the question of interest is whether these two programs offered by the VOD service can be of a higher quality than what the TV channel offers with two programs (at the same levels of δ and λ). We formally state the result as Proposition 3 below.

Proposition 3 *When the VOD service offers four programs* (V_4) *and the TV service offers two programs* (TV_2)*, the two high quality programs of the VOD service are set*
(i) to a higher quality than the TV's quality when $\lambda > \sqrt{3} - 1$ *and* $\delta > \dfrac{2-2\lambda}{\lambda}$*; and*
(ii) to a lower quality when $\lambda < \sqrt{3} - 1$ *or* $\delta < \dfrac{2-2\lambda}{\lambda}$.

We identify the region where the VOD quality is higher as the area marked IV and the region where the quality is lower as the area marked I(b) in Figure 6. We know that, with the four-program offering, the advantages of the VOD service over the TV channel increases with an increase in both δ and λ. The quality advantage (over the TV channel) comes from the ability to get all the viewers of a program to watch it in their preferred time, an advantage that is increasing in δ. So, offering a higher quality along with more programs is more likely at a higher δ (than lower δ), as can be verified easily from region IV of Figure 6. Whereas, in the region I(b) (of Figure 6), the program quality of the VOD service is lower than what the TV would have offered.

In Figure 7 we illustrate (for $\lambda = 0.8$) how the higher quality programs offered by the VOD service (the solid flat line) is lower, equal to and higher than the quality of the two programs offered by the TV channel (the dashed line). The figure illustrates how the availability of the program at all times means the higher quality programs (viewers' preferred-time choices) are not affected by δ (or λ). Whereas without this ability the TV channel cannot attract viewers whose preferred time is different from when the program

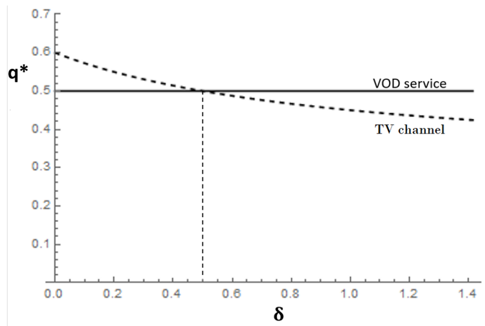

Figure 7: Comparative Statics of the Higher Quality w.r.t. δ in Cases V_4 and TV_2 at $\lambda = 0.8$

is airing. The quality of the TV programs steadily drops with an increase in δ. The figure illustrates (for $\lambda = 0.8$) how for $\delta > 0.5$ the qualities of the TV offering are lower.

VOD Service and Pareto Improvement

A question that follows naturally from the discussions on number of programs and their quality is of consumer welfare. As the VOD service is a superior mode of serving programs, one can expect consumer welfare to be higher. Think of it this way, even if the VOD service's offering is the same as the linear TV's there is more consumer welfare due to the flexibility accorded to viewers. We ask instead whether the VOD service is a Pareto improvement over the TV channel. We first compare the cases where the linear TV offers one program (TV_1) to VOD ((i)V_{2a}, (ii) V_{2s} and (iii) V_4). When the VOD service offers more programs (like in the above cases), it is a Pareto improvement if the VOD offering constitutes as many programs (as TV) at a higher (or equal) quality. In cases (ii) and (iii) above A-preferring viewers are served with a lower quality program of genre A, some among them (ones with a higher outside option) have no demand for a second program and therefore are worse off when served by a VOD service.

Now we compare the cases where the TV offers two programs (TV_2) to VOD ((i)V_{2a}, (ii) V_{2s} and (iii) V_4). While case (ii) is a Pareto improvement, case (iii) is a Pareto improvement only when the two high-quality programs are of a higher quality than the TV programs. This leaves case (i) where VOD offers one program of a higher and the other of a lower quality than the two programs offered on linear TV. The VOD service is a Pareto improvement if B-preferring viewers who in TV had a B-type program in their preferred time get a higher utility from (the higher quality) A-type program when served by VOD. However, this is not always the case and they can be worse off (when served by a VOD service) when genre preference is relatively strong (high λ).[21] The comparisons convey how, while VOD services are welfare-improving, the gains are not uniform across viewers. The discussion of case (iii) illustrates that while all the viewers who prefer a genre (A here) benefit, a section of viewers who prefer the other genre (B here) can be worse off.

6 Extension: Skewness in Preferred-time Distribution

So far we analyzed a setting where half the viewers preferred watching in t_1 and the other half in t_2. Here we relax this assumption and consider a setting in which more viewers prefer watching at a certain time, akin to prime time. Let $\gamma \in (\frac{1}{2}, 1]$ be the fraction of viewers who prefer watching in t_1 to t_2 and $(1-\gamma)$ the fraction of viewers who prefer watching in t_2 to t_1. A higher γ indicates that the viewers are less heterogeneous in their preferred time, which benefits the TV service. This is because the program shown in t_1 now gets a higher viewership, as it is the preferred time for more viewers. On the other hand, because the VOD anyway allows every viewer to watch any program in their preferred period, γ does not affect the demand for the VOD programs.

Proposition 1 discusses when the VOD service sets asymmetric qualities while offering two programs. As the decisions of the VOD service are invariant to how viewer the time preferences are distributed, Proposition 1 is unaffected by the change in the setting considered here.

When the distribution of the viewer time preferences is skewed, the TV channel has a higher marginal revenue (of quality) from the program shown in that time (t_1 here) and accordingly offers a higher quality program in the time preferred by more viewers (t_1

[21] They are worse off when $(1-\lambda)q_{V_{2a},A} < q_{TV_2,B}$ in the parameter range where VOD offers two programs at asymmetric qualities V_{2a}. This is true for $\frac{1}{2} < \lambda < 2-\sqrt{2}$.

here). To see this formally, let the program offered by the TV channel in t_1 be A, its quality $q_{TV_2,A}$ and the demand realized $D_{TV_2,A}(\delta, \lambda, \gamma)$, where this program is a prime-time show. Let B be the program shown in t_2 which is the preferred time of fewer ($1-\gamma$ proportion of) viewers $q_{TV_2,B}$ its quality and $D_{TV_2,B}$ the viewership realized. We express the demand realized as:

$$D_{TV_2,A} = \frac{\gamma q_{TV_2,A}}{2} + \frac{\gamma q_{TV_2,A}(1-\lambda)}{2} + \frac{(1-\gamma)q_{TV_2,A}}{2(1+\delta)} + \frac{(1-\gamma)q_{TV_2,A}(1-\lambda)}{2(1+\delta)}; \text{and} \quad (17)$$

$$D_{TV_2,B} = \frac{(1-\gamma)q_{TV_2,B}}{2} + \frac{(1-\gamma)q_{TV_2,B}(1-\lambda)}{2} + \frac{\gamma q_{TV_2,B}}{2(1+\delta)} + \frac{\gamma q_{TV_2,B}(1-\lambda)}{2(1+\delta)}. \quad (18)$$

The equations above are similar to Equations (7) and (8) except that γ (or $1-\gamma$) adjusts for the skewness in viewer time preference distribution. The cost of the two programs, like before, are $\frac{q^2_{TV_2,A}}{2}$ and $\frac{q^2_{TV_2,B}}{2}$, respectively. We obtain the qualities $q^*_{TV_2,A} = \frac{(1+\gamma\delta)(2-\lambda)}{2(1+\delta)}$ and $q^*_{TV_2,B} = \frac{(1+(1-\gamma)\delta)(2-\lambda)}{2(1+\delta)}$ that maximize the profits from showing the respective programs. With the expressions obtained for the program quality, we can proceed to examine the robustness of Propositions 2 and 3 when viewers' preferred time is not symmetrically distributed between t_1 and t_2[22].

Proposition 2 highlights how the VOD service can offer higher quality program(s) compared to the TV channel when either service offers the same number (two) of programs. We will examine the robustness of the result, now that the TV channel offers a higher

[22]We need to account for the TV channel's alternative option of showing the same program in both t_1 and t_2. Remember that, when there are equal proportion of viewers who preferred watching in t_1 to t_2 and the other way around ($\gamma = \frac{1}{2}$), the TV channel offers a single program when $\delta > \sqrt{2}$. Again the TV channel, when it chooses to offer a single program, it was not because a second program was unprofitable, but it was more profitable to make the same program available in both periods. But when a larger proportion of viewers prefer t_1 ($\gamma > \frac{1}{2}$), the opportunity cost of not making program A available in t_2 is lower and therefore there is less incentive now for the channel to offer just a single program. In other words, the channel is less likely to offer a single program compared to when viewer time preferences are symmetrically distributed.

quality program in t_1 (its prime time).

When the VOD service sets the programs to symmetric qualities, the incentive of the VOD service to offer a higher quality comes from its ability to show viewers a program matched to their taste in the time they prefer watching. Now, in TV, with a larger proportion of viewers preferring t_1, more A-preferring viewers can watch a program consistent with their taste in their preferred time and even fewer B-preferring viewers can watch a B-type program in their preferred time. We need to verify that (the higher quality) prime time show on TV could be of a lower quality than the two programs offered by the VOD service. We have expressions for $q^*_{V2s,A} = \frac{2+\delta-\lambda}{2(1+\delta)}$ and $q^*_{TV_2,A} = \frac{(1+\gamma\delta)(2-\lambda)}{2(1+\delta)}$ and need to check when the former is larger than the latter. The condition reduces to $\gamma < \frac{1}{2-\lambda}$. This means that, when the VOD offers two programs, the program quality is higher as long as $\gamma < \frac{1}{2-\lambda}$. This is what we expect. However, note that the threshold of skewness (γ) below which the VOD offering is of a higher quality is increasing in λ (the utility loss from taste mismatch) because when λ is high fewer B-preferring viewers watch A in t_1. For example, consider the case when $\lambda = 2 - \sqrt{2}$ and $\delta = 1$, we know from Lemma 3(b) that in this case, the VOD service offers two programs set to equal quality. Substituting these into the expressions above we get that the VOD programs are of a higher quality when $\gamma < \frac{1}{\sqrt{2}}$, i.e., the fraction of t_1-preferring viewers is less than approximately 70%.

Proposition 2 also conveys how the VOD service offers a higher quality when it sets both its programs A and B to asymmetric qualities. In this case, the higher quality program is the preferred choice for all the viewers. In TV, although now more viewers have t_1 as their preferred time, still all viewers cannot watch A (the program in t_1) in their preferred time (unless of course $\gamma = 1$). Similarly, while fewer viewers prefer watching in t_2, still some of the viewers who watch program B (offered by the TV channel in t_2) are watching it in their preferred time, whereas with VOD service the lower quality program is the lower utility program for all the viewers. So we expect the qualities of the two programs offered by the TV channel to lie in between the qualities offered by the VOD service, i.e.,

$q^*_{V2a,A} > q^*_{TV_2,A} > q^*_{TV_2,B} > q^*_{V2a,B}$ which is verified in Appendix A.8 .

Now we consider Proposition 3 which discusses the ability of the VOD service to offer higher quality programs even when offering more programs compared to what the TV channel offers. Recall that, when the VOD service offers four programs, the higher quality programs among them are offered at $q^*_{V4,A} = q^*_{V4,B} = \frac{1}{2}$. So we check under what conditions is $q^*_{TV_2,A}$ lower than $\frac{1}{2}$. The condition reduces to $\gamma < \frac{\lambda+\delta-1}{\delta(2-\lambda)}$, i.e., when the heterogeneity in time preference is not too large. This is intuitive because, as γ increases, VOD's advantage of making all programs available at all times reduces, as there are fewer viewers who prefer non-prime-time period. We can see that the right-hand side of the expression is increasing in δ and λ. We expect this because $q^*_{V4,A}$ and $q^*_{V4,B}$, the quality levels of the two higher quality (when VOD service is offering four programs), are independent of δ and λ, whereas the quality at which the TV channel offers its prime-time show $q^*_{TV_2,A}$ is decreasing in both δ and λ. From Lemma 3(c) we know that the VOD service offers four programs in the region $\sqrt{3} - 1 < \lambda < 1$ and $\frac{2-2\lambda}{\lambda} < \delta < \sqrt{2}$. Like before, consider the case where $\lambda = 0.8$ and $\delta = 1$. Substituting these into the expression we get $\gamma < \frac{2}{3}$ which indicates that the VOD service offers two higher quality programs as long as less no more than two-thirds of the viewership prefer t_1 to t_2.

7 Discussion and Conclusions

In this paper we describe how a VOD service makes its program decisions differently from a linear TV service. With VOD, the service's program decisions are not constrained by how viewer time preferences are distributed. As a result, the service can more flexibly set the qualities of the programs it offers. While program decisions of a VOD service have received significant press attention, they have seldom explored the "on-demand" feature of the service as a key difference between VOD and linear TV. While the advantages of the VOD service point to an improved offering, only the flexible quality setting arising from heterogeneity in viewer time preferences can explain why VOD programs could be offered at a lower quality compared to linear TV. We also see VOD service's advantage when viewers have strong genre preferences; it has the ability to get viewers to watch their preferred genre program in their preferred time. When it expands the number of programs to offer multiple programs of the same genre, it is the ability to be not constrained by heterogeneity in viewer time preference that allows the VOD service to still offer higher quality programs than the linear service. As budget of shows produced by TV or streaming services are not publicly available, we cannot empirically validate whether a streaming service's quality investments have a higher variance compared to a traditional TV channel. In Appendix A.9 we compare viewer ratings of Netflix and HBO between 2013 and 2019, a period where the latter was primarily a TV channel. We do see that in both dramas and comedies, ratings of Netflix shows are more broadly distributed compared to shows on HBO, consistent with analyst observations.

In the current work, the service earns revenue only through advertising which leads to a simple objective function— maximize total viewership (market coverage) net of costs. While advertising-based VOD services are not uncommon, there are others that earn revenues through pay-per-view or subscription pricing. Although we do not consider a case where the TV or the VOD service charges a price to its viewers, we note that our results will only strengthen if the firm instead charged the viewers directly. This is because, typically, charging a price to consumers allows any service to produce a greater quality program because of its greater ability to extract surplus from the consumers [Peitz and Valletti, 2008]. However, this incentive is higher for a VOD service because it can provide this program at a viewer's preferred time which creates a higher value for the program on the VOD service than on a TV channel.

Timeshift TV has been prevalent for some time and allows viewers to watch already aired programs at a time of their choice. This is usually achieved by recording the programs locally. More recently programs are also archived on the web, which viewers can watch at a convenient time. While time shifting is the key feature of VOD service that we study here, it is unclear whether traditional TV networks were considering time shifting ability of viewers into their program decisions. In case the decisions were influenced, we would have some the same content production implications with both VOD and the time-shift TV technologies.

Many extensions of interest remain. Our analysis has been conducted in a full information setting. The VOD service, implemented as an online service has significant data collection advantages over traditional TV, potentially giving them a better targeting ability. If the literature on TV economics is a guide, the service models that emerge to provide VOD should lead to interesting analyses. Our work in this paper is to illustrate the titular difference of a VOD service, the ability to make available programs on-demand; and how it changes the programming decisions. With this, we make the case that future work studying VOD services, should not ignore the effects of time preference as illustrated here.

A Appendix

A.1 Proof of Lemma 1

Let p_1 and p_2 be the two programs that give viewer ω the highest and the second highest utilities ($u_1 \geq u_2$) from all the programs offered. Then, watching p_1 (or p_2) in the preferred period gives the viewer a net utility of $u_1 - \omega$ (or $u_2 - \omega$), and watching p_1 (p_2) in the less-preferred period gives the viewer a net utility of $u_1 - (1 + \delta)\omega$ (or $u_2 - (1 + \delta)\omega$). Note that, irrespective of when the viewer watches the two programs, the total utility they get are the same ($= u_1 + u_2 - (2 + \delta)\omega$) in both the cases. However, if $u_2 - \omega > 0 > u_2 - (1 + \delta)\omega$, then the viewer gets a higher utility from only watching one program (p_1) in the preferred period than watching p_2 in preferred time and p_1 in less-preferred time, as $u_1 - \omega > u_1 + u_2 - (2 + \delta)\omega$. Therefore, a viewer is always weakly better off watching the program with the highest utility in their preferred time.

A.2 Proof of Proposition 1

We have obtained expressions for the profits realized by the VOD service when setting programs to asymmetric and symmetric qualities as $\Pi_{V2a} = \frac{(\lambda-2)^2(2+\delta^2+2\delta)}{8(1+\delta)^2}$ and $\Pi_{V2s} = \frac{(2+\delta-\lambda)^2}{4(1+\delta)^2}$ respectively (see Table 3). For Proposition 1 we need the region where $\Pi_{V2a} > \Pi_{V2s}$ which can be reduced to $\delta > \frac{4\lambda-2\lambda^2}{2-4\lambda+\lambda^2}$. As $\delta \in \mathbb{R}_+$, $\delta > \frac{4\lambda-2\lambda^2}{2-4\lambda+\lambda^2}$ is valid when $0 < \lambda < 2-\sqrt{2}$, which is the range identified in Proposition 1.

A.3 Proof of Corollary 1

We have obtained the expression for the service's profit when offering four programs, two of whose qualities are higher than the other two as $\Pi_{V_4} = \frac{2+\delta^2+2\delta}{4(1+\delta)^2}$. From Table 4 recall the viewership realised (by a program) when all four programs are offered at the same quality as $\frac{q_{V_4,i}}{4} + \frac{q_{V_4,i}}{4(1+\delta)}$ where $i \in \{A, B\}$. The quality at which they will be offered is $\frac{(2+\delta)}{4(1+\delta)}$ and the profit realised by one of them is $\frac{(2+\delta)^2}{32(1+\delta)^2}$. The service's profit by setting all four programs to the same quality will be $\frac{(2+\delta)^2}{8(1+\delta)^2}$, less than Π_{V_4}.

A.4 Proof of Lemma 2

The profit when offering a single program and two programs are respectively $\Pi_{TV_1} = \frac{(-2+\lambda)^2}{8}$ and $\Pi_{TV_2} = \frac{(2+\delta)^2(2-\lambda)^2}{16(1+\delta)^2}$ (see Table 2). Π_{TV_2} can be expressed as $= \frac{(-2+\lambda)^2}{8} \times \frac{(2+\delta)^2}{2(1+\delta)^2}$. To see when $\Pi_{TV_2} > \Pi_{TV_1}$ it is sufficient to check when $\frac{(2+\delta)^2}{2(1+\delta)^2} > 1$; one can verify that the function is decreasing in δ and the numerator equals the denominator when $\delta = \sqrt{2}$, indicating that $\frac{(2+\delta)^2}{2(1+\delta)^2} > 1$ when $\delta < \sqrt{2}$, which is the statement of Lemma 2.

A.5 Proof of Lemma 3

A.5.1 V_1 is not offered

We first show that offering V_1 is always less profitable than offering V_{2a} and therefore need not be considered further. We know $\Pi_V = \frac{(2-\lambda)^2(2+\delta^2+2\delta)}{8(1+\delta)^2} > \Pi_{V_1} = \frac{(2-\lambda)^2}{8}$ $\forall\ \delta > 0$ and $\lambda \in (0, 1)$.

A.5.2 V_3 is not offered

Next we show that offering V_3 is not offered, as the profits realized by V_3 is always lower than other offerings. Specifically, (i) $\Pi_{V_{3i}} < Max\{\Pi_{V_{2s}}, \Pi_{V_4}\}$ and (ii) $\Pi_{V_{3ii}} < Max\{\Pi_{V_{2a}}, \Pi_{V_4}\}$ $\forall\ \delta > 0$ and $\lambda \in (0, 1)$. In other words, V_3 offered in either quality configuration generates lower profits than other offerings.

A.5.3 Lemma 3(a):

The statement of Lemma 3(a) gives the range of λ and δ where V_{2a} is the most profitable offering, i.e., $\Pi_{V_{2a}} > \Pi_{V_{2s}}$ **and** $\Pi_{V_{2a}} > \Pi_{V_4}$. We know from Proposition 1 the region where $\Pi_{V_{2a}} > \Pi_{V_{2s}}$ as $\delta > \frac{4\lambda-2\lambda^2}{2-4\lambda+\lambda^2}$ and $\lambda < 2-\sqrt{2}$. To verify whether in this region $\Pi_{V_{2a}}$ is also greater than Π_{V_4}, we just need to verify $\frac{(2-\lambda)^2}{2} > 1$. This is true when $\lambda < 2-\sqrt{2}$.

A.5.4 Lemma 3(b):

The statement of Lemma 3(b) gives the range of λ and δ where V_{2s} is the most profitable offering i.e. $\Pi_{V_{2s}} > \Pi_{V_{2a}}$ **and** $\Pi_{V_{2s}} > \Pi_{V_4}$. We know (from Proposition 1) that when $\lambda < 2-\sqrt{2}$, $\Pi_{V_{2a}} > \Pi_{V_{2s}}$ if $\delta \leq \frac{4\lambda-2\lambda^2}{2-4\lambda+\lambda^2}$; we also know from 3(a) above, that $\Pi_{V_{2a}} > \Pi_{V_4}$ when $\lambda < 2-\sqrt{2}$. So V_{2s} is the dominant offering when $\delta \leq \frac{4\lambda-2\lambda^2}{2-4\lambda+\lambda^2}$ and $0 < \lambda < 2-\sqrt{2}$.

Now we check what region (where $\lambda > 2-\sqrt{2}$) has $\Pi_{V_{2s}} > \Pi_{V_4}$, which reduces to $\delta < \frac{4\lambda-2\lambda^2}{2-4\lambda+\lambda^2}$. At $\lambda = 2-\sqrt{2}$, $\Pi_{V_{2s}}$ dominates the two other offerings for all δ.

A.5.5 Lemma 3(b):

We verify when is Π_{V_4} the most profitable offering. We know from 3(a) that $\Pi_{V_4} > \Pi_{V_{2a}}$ when $\lambda > 2 - \sqrt{2}$. From 3(b) we know $\Pi_{V_{2s}} > \Pi_{V_4}$ when $\delta < \frac{4\lambda - 2\lambda^2}{2 - 4\lambda + \lambda^2}$. So, the four program offering is the choice when $2 - \sqrt{2} < \lambda < 1$ and $\delta > \frac{4\lambda - 2\lambda^2}{2 - 4\lambda + \lambda^2}$.

A.6 Proof of Proposition 2

The Proposition 2 is verified when $q^*_{V_{2a},A} = \frac{(2-\lambda)}{2} > q^*_{TV_2} = \frac{(2+\delta)(2-\lambda)}{4(1+\delta)}$ and $q^*_{V_{2s},A} = \frac{(2+\delta-\lambda)}{2(1+\delta)} > q^*_{TV_2} = \frac{(2+\delta)(2-\lambda)}{4(1+\delta)}$. The first inequality holds for all positive δ. The second inequality too holds for the full range of δ and λ.

A.7 Proof of Proposition 3

From Table 5 we know when the VOD service is offering 4 programs, the quality level of the two higher quality programs among them is $\frac{1}{2}$. We know (*see* Table 2) the quality of the programs offered by the TV channel when offering 2 programs is $\frac{(2+\delta)(2-\lambda)}{4(1+\delta)}$. We need the region where $\frac{1}{2} > \frac{(2+\delta)(2-\lambda)}{4(1+\delta)}$, which also falls in the region where VOD is offering four programs ($(2-\sqrt{2}) < \lambda < 1$ and $0 < \delta < \frac{2-4\lambda+\lambda^2}{-2+2\lambda}$) and TV channel is offering two programs ($0 < \delta < \sqrt{2}$). The original condition reduces to $\delta > \frac{2-2\lambda}{\lambda}$. We need to check, for what values of $\lambda > 2 - \sqrt{2}$ is $\frac{2-2\lambda}{\lambda} > \frac{2-4\lambda+\lambda^2}{-2+2\lambda}$ i.e. for what portion of the region identified by $\delta > \frac{2-2\lambda}{\lambda}$ is the four program offering not the dominant choice (see Figure 6). The two expressions are equal at $\sqrt{3} - 1$, meaning the region identified by $\delta > \frac{2-2\lambda}{\lambda}$ intersects the four program region only from $\sqrt{3} - 1 < \lambda < 1$.

A.8 Verification of Claim in Extension

Claim: $q^*_{V2a,A} > q^*_{TV_2,A} > q^*_{TV_2,B} > q^*_{V2a,B}$.

Here the expressions for TV program qualities are for when $\gamma > \frac{1}{2}$. We already know the program shown in t_1 (A here) is set to a higher quality i.e. $q^*_{TV_2,A} > q^*_{TV_2,B}$. To verify the claim we need to check whether $q^*_{V2a,A} > q^*_{TV_2,A}$ and $q^*_{TV_2,B} > q^*_{V2a,B}$. We have expressions for all of these qualities. With $q^*_{V2a,A} = \frac{(2-\lambda)}{2}$ and $q^*_{TV_2,A} = \frac{(1+\gamma\delta)(2-\lambda)}{2(1+\delta)}$, we know the former is greater as $\frac{(1+\gamma\delta)}{(1+\delta)} < 1$. With $q^*_{TV_2,B} = \frac{(1+(1-\gamma)\delta)(2-\lambda)}{2(1+\delta)}$ and $q^*_{V2a,B} = \frac{(2-\lambda)}{2(1+\delta)}$, we again know the former is greater. This completes the verification of the claim.

A.9 Ratings Comparison: Streaming and TV

We compare viewer ratings of shows offered on Netflix and HBO between 2013 and 2019. We obtained the IMDB ratings of all 20 dramas and 20 comedies that debuted on HBO in the period and all english language series that debuted on Netflix in the corresponding period, 56 dramas and 60 comedies. The histograms are plotted below.

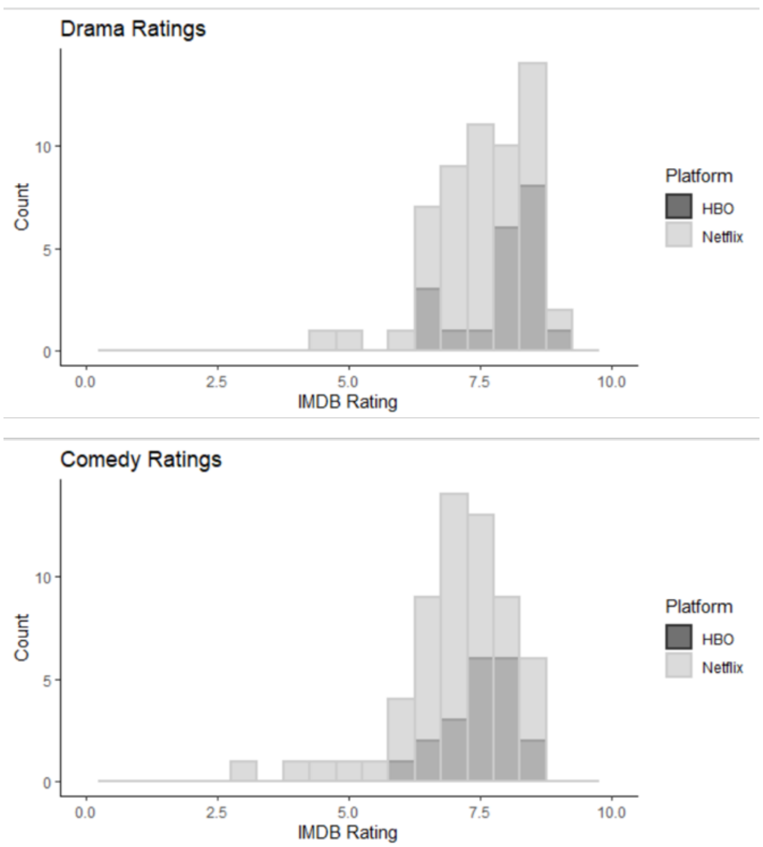

Figure 8: IMDB rating: HBO and Netflix

We note that Netflix offers more high quality programs than HBO, while the average rating is lower. In other words, Netflix ratings have a higher variance compared to HBO.

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