TV programming choice under public funding*

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Preliminary version

Abstract

A model of public funding in the broadcasting market is developed. It is examined how public funding affects the type of program a commercial broadcasting station shows. To this end, a commercial broadcasting station decides on its advertising level and chooses between a socially preferable and a socially less preferable type of program. It is first shown that there may be asymmetric equilibria where two commercial stations choose different types of programs if there is no public funding. If there is a public-service broadcaster which receives parts of a license fee and which has to show the socially preferable type of program, this may increase the commercial broadcasting station's incentive to opt for this type of program as well.

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1 Introduction

Over the past years, there has been an intense debate under way as to whether public funding of broadcasting companies in Europe hurts commercial competitors and should therefore be abolished. Public funding is a non-negligible aspect of the European broadcasting market as it is a common practice in almost all European countries (and beyond). It accounts for several billion € that are transferred to public-service broadcasters throughout Europe alone every year. There are different forms of public funding in Europe reaching from a license fee (television/radio license) only (e.g., SVERIGES RADIO [STR/SR] in Sweden), a license fee together with advertising (e.g., FRANCE TELEVISIONS in France), and a license fee, advertising plus government grants (e.g., RADIOTELEVISAO PORTUGUESA [RTP] in Portugal).[1] However, commercial stations have always regarded public funding an illegal distortion of competition among broadcasting firms. Therefore, the EUROPEAN COMMISSION had to decide on the way public funding is being treated in various European countries. In 2001, the EUROPEAN COMMISSION applied the so-called state-aid rules to public-service broadcasting carrying out decisions on RAI in Italy, France 2 and 3 as well as RTP in Portugal.[2] In 2004, the EUROPEAN COMMISSION ruled that the Danish public-service broadcaster TV2 had to pay back DKK 628.2 (€ 84.4) million to the Danish state. The EUROPEAN COMMISSION considered this sum not proportionate to the net cost of providing the public service and found it an illegal state aid.[3]

Last year Germany saw a rather controversial discussion as to whether to extend the scope of the license fee. The prime ministers of the 16 German states decided that the license fee should also be paid by those owning an Internet-compatible personal computer/notebook or mobile phone if they do not already pay the fee.[4] It is argued that programs broadcast by public-service broadcasters can be (partly) watched or listened to through the Internet which makes the levying of the license fee possible.

This paper aims to contribute to the growing literature of competition in the broadcasting market applying the concept of two-sided markets with a special focus on public funding. Despite the political attention that has been

[1] See EUROPEAN BROADCASTING UNION (2006).

[2] See DEPYERE, BROCHE, and TIGCHELAAR (2001).

[3] See "Commission orders Danish public broadcaster TV2 to pay back compensation for public service task," press release by the EUROPEAN COMMISSION, May 19, 2004, IP/04/666 [hereinafter EUROPEAN COMMISSION, *TV2*].

[4] See "GEZ-Gebühr für Internet-Computer beschlossen," SPIEGEL ONLINE, October 19, 2006, available at `www.spiegel.de/netzwelt/web/0,1518,443606,00.html`.

paid to the topic recently, theoretical models explaining the economic impact of a state-imposed license fee in the broadcasting market are rare. The present approach is related to several existing models and combines some of their features. The seminal contribution which analyzes competition among broadcasting companies from the perspective of a two-sided market is due to Anderson and Coate (2005). As a two-sided market[5], the broadcasting market brings together advertisers and viewers where advertisers are interested in paying for advertising time only if there are (enough) viewers watching the respective program. Viewers, however, dislike advertising.[6] In their work Anderson and Coate (2005) are mainly interested in the optimal provision of advertising and the nature of market failure in the industry. They show that advertising can either be under- or oversupplied and that an unambiguous advice concerning the regulation of advertising levels cannot be given.

Their canonical model is extended by Kohlschein (2005) to allow for public funding for the first time. He considers the effects of the introduction of public funding on competition among a public-service broadcaster and a commercial broadcasting company. Kohlschein (2005) shows that public funding decreases the public-service broadcaster's advertising level. At the same time, the commercial station also has to decrease its advertising level—to a lesser extent than the public channel though. Hence, there is an asymmetric equilibrium where the public-service broadcaster has a larger market share. The author also shows that the introduction of a license fee may increase social welfare if the nuisance from advertising is high and if the channels' substitutability is rather low.

The model presented here also makes use of Papandrea (1997) to capture the 'breadth of appeal' of different programs. Basically, this means that broadcasting stations can choose between different types of programs leading to different degrees of substitutability.

Another paper that is also related to the present one is due to Doyle (1998). In his model without public funding, two stations choose between two program types each of which is preferred by different groups of viewers. What is different with the present setup, though, is the lack of competition in advertising levels and of (additional) differentiation between the channels. The latter, however, is essential for competition between a public-service broadcaster and the commercial station to make sense as will become clear later.

[5]For an introduction to the economics of two-sided markets, see Rochet and Tirole (2003) and Armstrong (2005b).

[6]See also Kind, Nilssen, and Sørgard (2005). Reisinger (2004) uses the concept of negative externalities to analyze the advertising behavior of Internet portals and the like in a similar way.

Most models concerning public-service broadcasting are all missing one important aspect: The key justification put forward in favor of public funding is that—besides being entertaining—public-service broadcasting is a way to inform and educate people. This is the case, for instance, in Germany and the United Kingdom.[7] An exception is ARMSTRONG (2005a): He defines quality as enhancing viewers' utility and shows that if the public-service broadcaster increases its quality the commercial one will not do so too—instead, it will decrease its own quality level. This is due to the fact that an increase in (costly) quality on the public-service broadcaster's side decreases the commercial station's market share which in turn reduces its return on quality investment. Although he considers the case of pay-TV/subscription programs, his analysis can be readily compared with the one in the present paper since here advertising levels can be interpreted as indirect prices in the utility function.

CANOY and NAHUIS (2005) also examine whether public-service broadcasting (without public funding) has a positive effect on a commercial station's quality decision. Different from the present approach, commercial stations maximize audience and the public-service broadcaster maximizes welfare by choosing an optimal level of quality. They also look at the strategic aspect of the order of programming decisions (mimicking vs. counter-programming). They find that public-service broadcasting may either increase the quality of the public-service broadcaster (by inducing more counter-programming) or the one of the commercial channel. However, as quality levels are strategic substitutes, such increases come at the expense of a decreased quality level by the other station. Overall effects are ambiguous depending among others on the relative importance of the commercial station's quality in the welfare function. Contrary to that, this paper assumes that there is public funding and that program quality is equally relevant independent of whether it is provided by the public-service broadcaster or the commercial station.

More precisely, it is assumed that quality—though socially desirable—does not necessarily enhance an individual viewer's utility but may indeed have the contrary effect. In the benchmark case without public funding, there are two commercial stations which have to decide which type of program to show: a socially less preferable or a socially preferable one. It is shown that there may be asymmetric equilibria where both channels show different types of programs. If there is a public-service broadcaster which receives a license fee and—contrary to the contributions mentioned above—*has to* show the socially preferable program, the commercial station may be induced to

[7] In Germany the goal of education is written down in the broadcasting law (the so-called *Rundfunkstaatsvertrag* [*RStV*]).

follow suit although it would not do so without public funding.
The paper is organized as follows. The next section introduces the model and analyzes the benchmark case without public funding first. Then, the effects of public funding on the programming choice of a commercial station are examined. Section 3 concludes. Proofs are relegated to the appendix.

2 The model

In this section the model is presented. Before turning to the case of competition between a public-service broadcaster and a commercial station, the benchmark case without public funding is considered.

2.1 Benchmark: no public funding

There are two commercial broadcasting companies. Suppose that station 1 (its program portfolio) is located at 0 of the HOTELLING (1929) line of unit length whereas channel 2 is located at 1. Suppose further that a commercial broadcasting station can offer one of two types of programs: one that is socially less preferable (denoted by L) or a second one that is socially preferable (denoted by H), i.e. station i's strategy set is given by $s_i \in \{L, H\}$ with $i \in \{1, 2\}$. Broadcasting companies' marginal costs are normalized to 0. It is assumed that the fixed costs for showing the socially preferable type of program (denoted by F) are higher than the ones for the socially less preferable type of program which are normalized to 0 too. This assumption may be particularly true for news programs which require correspondents, offices, and other equipment in a lot of countries. The same may be true for costly documentaries or magazines. It may not be appropriate for large international movie productions whose licenses often have to be bought at a rather high price.
Both broadcasting companies generate revenues from placing commercials before, during, and/or after their programs. The level of advertising is denoted by $a_i^{s_i|s_j}$ for $i \neq j$. For simplification, let $a_i^{s_i|s_j} = a_i^{s_i}$ whenever $s_i = s_j$. Stations get certain advertising revenue which represents the market price for reaching one viewer. Hence, broadcasting firms are quantity setters, i.e. they maximize profits with respect to the advertising level. This follows standard modeling assumptions in the literature. Furthermore, it reflects real-life experience: In Germany, for example, both public-service broadcasters and the largest commercial stations together conduct market research with respect to the development of the advertising price per thousand viewers.[8]

[8]See `www.agf.de`.

Viewers of mass 1 are uniformly distributed along the HOTELLING (1929) line. It is natural to assume that viewers singlehome, i.e. only watch one program at a time or over a period of time, respectively. Two groups of viewers will be considered. The utility for a viewer within one of the two groups (denoted by superscripts I and II) located at x from watching channel i can thus be written as

$$u_i^I = \begin{cases} \beta_h - \gamma a_i^{L|s_j} - \frac{1}{\tau_l}x & \text{if } s_i = L \\ \beta_l - \gamma a_i^{H|s_j} - \frac{1}{\tau_h}x & \text{if } s_i = H \end{cases} \tag{1}$$

and

$$u_i^{II} = \begin{cases} \beta_l - \gamma a_i^{L|s_j} - \frac{1}{\tau_h}x & \text{if } s_i = L \\ \beta_h - \gamma a_i^{H|s_j} - \frac{1}{\tau_l}x & \text{if } s_i = H. \end{cases} \tag{2}$$

In line with most papers dealing with this type of market, it is assumed that viewers are annoyed by commercials the extent of which is measured by a nuisance parameter γ with $\gamma > 0$. As far as quality is concerned, in this paper it is argued that—unlike in ARMSTRONG (2005a)—quality is a rather vague concept in the context of broadcasting: Not every type of program that is considered to be of higher quality (e.g., as it touches upon subjects related to culture, news, science, etc.) from the viewpoint of society as a whole is necessarily seen as such by the individual viewer. Therefore, the model considered here includes two groups of viewers within society. Both groups differ in their basic valuation (denoted by β_k where $k \in \{l,\ h\}$ and $\beta_l < \beta_h$) for the program that is qualitatively better from a social point of view. For the first group (a fraction α within society, superscript I), the socially preferable type of program is defined as yielding a lower basic utility. On the other hand, interests are indeed aligned with what is socially preferable for the second group (fraction $1-\alpha$, superscript II). Hence, every viewer derives a basic utility from watching a certain type of program where this basic utility is greater if the program type is the preferred one.
However, besides the program *type*, the program *characteristics* are also important to viewers. These characteristics are captured by the space between the two broadcasting companies' program portfolios. The closer a viewer is located to a portfolio, the less the difference between the viewer's preferred program characteristics and the actual characteristics. The extent of disutility brought about by the distance between preferred and actual characteristics is measured by the aforementioned breadth of appeal. This breadth of appeal is lower (higher) when watching the more (less) preferred type of program, i.e. viewers' loss of utility is given by $\frac{1}{\tau_k}$ per unit of distance where

$\tau_l < \tau_h$. The idea behind this specification is the following. Generally speaking, a viewer wishes to watch her or his preferred type of program. However, whenever doing so, she or he is more sensitive with respect to the program characteristics like actors, host, presenters, etc. E.g., a viewer may have to decide whether to watch a political talk show or a movie. This viewer usually has a preferrence (possibly varying over time) for one of them. When making his decision, though, she or he will typically take into account the talk shows guests and the actors in the movie as well.
Note that given this utility specification, it is clear that inducing broadcasting stations to show the socially preferable type of program may lead to a (possibly high) utility loss for individual viewers. However, it is assumed that even if this type of program may hurt viewers, it is beneficial to society as a whole. This means that the loss in utility as well as the decrease in profits for the commercial broadcasting station are always compensated for.[9] Note further that this approach differs to some extent from the one in PAPANDREA (1997): Unlike here, the author assumes that the second broadcasting station may choose to locate either at the exact same position like the first one or at some distance away from it which is interpreted as offering the same or a different program, respectively. Only in the second case, there is a different breadth of appeal. As will become clear later, this approach would not make sense here as a commercial broadcasting station would never choose the same location as a public-service broadcaster since the latter always has an advantage with respect to the competition in advertising levels.
Before turning to the equilibrium analysis, the following assumption is made:

Assumption 1 *If* $\alpha \leq \frac{1}{2}$, *then* $\beta^{\min}_{\alpha\leq\frac{1}{2}} \equiv \max\{0, \frac{-2(2-\alpha)\tau_l+(1-2\alpha)\tau_h}{(5-4\alpha)\tau_l\tau_h}\} \leq \beta \leq \frac{-(1-2\alpha)\tau_l+2(2-\alpha)\tau_h}{(5-4\alpha)\tau_l\tau_h} \equiv \beta^{\max}_{\alpha\leq\frac{1}{2}}$. *If* $\alpha > \frac{1}{2}$, *then* $\beta^{\min}_{\alpha>\frac{1}{2}} \equiv \max\{0, \frac{-2(1+\alpha)\tau_l-(1-2\alpha)\tau_h}{(1+4\alpha)\tau_l\tau_h}\} \leq \beta \leq \frac{(1-2\alpha)\tau_l+2(1+\alpha)\tau_h}{(1+4\alpha)\tau_l\tau_h} \equiv \beta^{\max}_{\alpha>\frac{1}{2}}$.

This assumption ensures that the market size does not exceed 1.[10] It also ensures that the market is always covered.[11]

Profits are denoted by $\pi_i^{s_i|s_j}$ for $i \neq j$. Again, let $\pi_i^{s_i|s_j} = \pi_i^{s_i}$ whenever $s_i = s_j$. Hence, the simultaneous one-shot programming-choice/advertising

[9] As CANOY and NAHUIS (2005) point out, one may think of the benefit of educated and informed citizens to society and democracy.

[10] Note that this assumption is not restrictive. It is a standard HOTELLING (1929) assumption which is somewhat more complex due to the amount of parameters involved and the fact that there are two groups of viewers. For a derivation of the bounds, see the appendix.

[11] This is in contrast to DOYLE (1998) who considers the possibility to switch off, i.e. there is an outside option.

game has the following structure:

		Station 2 L	Station 2 H
Station 1	L	π_1^L, π_2^L	$\pi_1^{L\|H}, \pi_2^{H\|L} - F$
	H	$\pi_1^{H\|L} - F, \pi_2^{L\|H}$	$\pi_1^H - F, \pi_2^H - F$

Table 1: Programming-choice/advertising game

The focus will be on pure-strategy equilibria only given that broadcasting stations are symmetric. To this end one has to distinguish between three cases: (i) Both stations opt for the socially less preferable type of program; (ii) both stations show the socially preferable type of program; and (iii) channels show different types of programs.

Both channels show program L

Suppose first that both broadcasting companies show the socially less preferable type of program. The indifferent viewer in the first group who also determines the market share $v_i^{I,L}$ of the first broadcasting station is found by solving

$$\beta_h - \gamma a_i^L - \frac{1}{\tau_l} v_i^{I,L} = \beta_h - \gamma a_j^L - \frac{1}{\tau_l}\left(1 - v_i^{I,L}\right)$$

for $v_i^{I,L}$:

$$v_i^{I,L} = \frac{1}{2} - \frac{\gamma\tau_l(a_i^L - a_j^L)}{2}. \tag{3}$$

Accordingly, solving

$$\beta_l - \gamma a_i^L - \frac{1}{\tau_h} v_i^{II,L} = \beta_l - \gamma a_j^L - \frac{1}{\tau_h}\left(1 - v_i^{II,L}\right)$$

for $v_i^{II,L}$ gives

$$v_i^{II,L} = \frac{1}{2} - \frac{\gamma\tau_h(a_i^L - a_j^L)}{2}. \tag{4}$$

Profit for firm i thus amounts to

$$\pi_i^L = a_i^L r\left(\alpha\left(\frac{1}{2} - \frac{\gamma\tau_l(a_i^L - a_j^L)}{2}\right) + (1-\alpha)\left(\frac{1}{2} - \frac{\gamma\tau_h(a_i^L - a_j^L)}{2}\right)\right). \tag{5}$$

Given that channels are symmetric, firm i will set the advertising level at

$$a_i^L = \frac{1}{\gamma(\alpha\tau_l + (1-\alpha)\tau_h)}. \tag{6}$$

As both firms attract half of the viewers of each group, profits are given by

$$\pi_i^L = \frac{r}{2\gamma(\alpha\tau_l + (1-\alpha)\tau_h)}. \tag{7}$$

Both channels show program H

Performing the same analysis as in the previous case leads to the following equilibrium advertising level:

$$a_i^H = \frac{1}{\gamma((1-\alpha)\tau_l + \alpha\tau_h)}. \tag{8}$$

Firms' profits thus amount to

$$\pi_i^H = \frac{r}{2\gamma((1-\alpha)\tau_l + \alpha\tau_h)}. \tag{9}$$

Different programming choice

Before turning to the equilibrium analysis, define the difference in basic utilities from watching one's preferred and one's less preferred type of program as $\beta \equiv \beta_h - \beta_l$.
Suppose that station i chooses the socially preferable type of program whereas the other broadcaster opts for the socially less preferable type of program. In such a situation, equilibrium advertising levels are given by

$$a_i^{H|L} = \frac{(2-\alpha)\tau_l + (1+\alpha)\tau_h + (1-2\alpha)\beta\tau_l\tau_h}{3\gamma\tau_l\tau_h} \tag{10}$$

and

$$a_j^{L|H} = \frac{(1+\alpha)\tau_l + (2-\alpha)\tau_h - (1-2\alpha)\beta\tau_l\tau_h}{3\gamma\tau_l\tau_h}. \tag{11}$$

These levels lead to market shares of

$$v_i^{I,H|L} = \frac{-\tau_l(1-2\alpha) + 2(2-\alpha)\tau_h - (5-4\alpha)\beta\tau_l\tau_h}{3(\tau_l + \tau_h)} \tag{12}$$

and

$$v_i^{II,H|L} = \frac{2(1+\alpha)\tau_l + (1-2\alpha)\tau_h + (1+4\alpha)\beta\tau_l\tau_h}{3(\tau_l+\tau_h)}. \tag{13}$$

Finally, equilibrium profits then amount to

$$\pi_i^{H|L} = \frac{r((2-\alpha)\tau_l + (1+\alpha)\tau_h + (1-2\alpha)\beta\tau_l\tau_h)^2}{9\gamma\tau_l\tau_h(\tau_l+\tau_h)} \tag{14}$$

and

$$\pi_j^{L|H} = \frac{r((1+\alpha)\tau_l + \tau_h(2-\alpha) - (1-2\alpha)\beta\tau_l\tau_h)^2}{9\gamma\tau_l\tau_h(\tau_l+\tau_h)}. \tag{15}$$

Comparison of profits

Looking at the different incentives to show the socially preferable type of program reveals the following:

Lemma 1 For any parameter values, $\pi_i^{H|L} - \pi_i^L > \pi_i^H - \pi_i^{L|H}$.

Proof See the appendix. ■

Next, consider one channel's incentives to opt for the socially desirable type of program if the other station shows the socially less preferable type:

Lemma 2 If $\alpha \leq \frac{1}{2}$, then $\pi_i^{H|L} - \pi_i^L > 0$. If $\alpha > \frac{1}{2}$, then $\pi_i^{H|L} - \pi_i^L \lesseqqgtr 0 \Leftrightarrow$ $\beta \gtreqqless \frac{-4\alpha\tau_l\tau_h(1-\alpha)+2\alpha\tau_l^2(2-\alpha)+2\tau_h^2(1-\alpha^2)+4\tau_l\tau_h-3\sqrt{2\tau_l\tau_h^3(1-\alpha)+2\tau_l^2\tau_h(\alpha\tau_l+\tau_h)}}{2(2\alpha-1)(\alpha\tau_l+(1-\alpha)\tau_h)\tau_l\tau_h} \equiv \beta^{\mathrm{L2}}_{\alpha>\frac{1}{2}}$.

Proof See the appendix. ■

Finally, one channel's incentives to opt for the socially desirable type of program if the other station also shows this type of program are given by:

Lemma 3 If $\alpha > \frac{1}{2}$, then $\pi_i^H - \pi_i^{L|H} < 0$. If $\alpha \leq \frac{1}{2}$, then $\pi_i^H - \pi_i^{L|H} \lesseqqgtr 0 \Leftrightarrow$ $\beta \lesseqqgtr \frac{-4\alpha\tau_l\tau_h(1-\alpha)+2\tau_l^2(1-\alpha^2)+2\alpha\tau_h^2(2-\alpha)+4\tau_l\tau_h+3\sqrt{2\tau_l^3\tau_h(1-\alpha)+2\tau_l\tau_h^2(\tau_l+\alpha\tau_h)}}{2(1-2\alpha)((1-\alpha)\tau_l+\alpha\tau_h)\tau_l\tau_h} \equiv \beta^{\mathrm{L3}}_{\alpha\leq\frac{1}{2}}$.

Proof The proof goes along the lines of the one for *Lemma 2* and is therefore omitted here. ■

Lemmas 1–3 have an intuitive implication. They indicate that a broadcasting station is more likely to show the socially desirable type of program if (i) the share of viewers who prefer this type of program over the other increases and (ii) if the other channel does not opt for it at the same time.

Both aspects make it possible to attract more viewers and to raise advertising levels by showing the socially preferable type of program. As a result profits are increased.[12]
Whether the commercial broadcasting stations decide to show the socially preferable type of program now depends on its fixed costs. Making use of *Lemmas 1–3*, one obtains:

Proposition 1 *The equilibria in the programming-choice/advertising game are determined by F:*

(i) *If* $F < \pi_i^H - \pi_i^{L|H}$ *and* $\alpha \leq \frac{1}{2}$, *then* $s_i = s_j = H$.

(ii) *If* $\pi_i^H - \pi_i^{L|H} < F < \pi_i^{H|L} - \pi_i^L$, *then* $s_i = L \wedge s_j = H \; \forall \; i, j \in \{1, 2\}, i \neq j$.

(iii) *If* $F > \pi_i^{H|L} - \pi_i^L$, *then* $s_i = s_j = L$.

The proposition shows that choosing the socially preferable type of program may be a dominant strategy for the stations. This is true if—not surprisingly—the costs for the program are not too high, i.e. the higher the profit margin that can be gained through this type of program. Note that both channels never simultaneously opt for the socially preferable type of program if the number of viewers who do not consider it their preferred program is the majority. In this case, given that the competitor shows the socially preferable type of program, a station would always benefit from choosing the second type of program thus catering to the interests of the majority. Interestingly, there are asymmetric equilibria where the two channels show different programs.[13] This may explain the observation in real-life broadcasting markets which are usually characterized by the coexistence of both high-quality and low-quality programs even in the absence of public funding. This is true in Germany, for example, where—leaving aside public-service broadcasters—commercial channels differ to quite a large extent when it comes to the quality of their news programs. Some of them do not even show any at all. In the USA where there is no public funding, there are large news networks or documentary channels while other stations only show entertainment programs (sitcoms, movies, etc.).
Given the different types of equilibria, there are two scenarios where a social planner would want to intervene since at least one broadcasting station does

[12] See also *Table 2* below for a numerical example.

[13] See also DOYLE (1998). However, in his setup advertising levels are exogenous. One may argue, though, that setting an advertising level is one of the key strategic variables for broadcasting companies.

not offer the socially preferable type of program. The following analysis will focus on the question whether the introduction of a license fee may alleviate this problem.

anmerkung: hartwich zu working paper von ANDERSON and COATE (2005): a. program type; anderes ergebnis als hier (abh. von tau bei beta=0) – and. spezifikation für advertising

2.2 Public funding

Suppose now that there is a public-service broadcaster (denoted by subscript p) located at 0 while the second station, a commercial broadcaster (denoted by subscript c), is located at 1. Although viewers do not have to pay anything to watch their favorite program—except for the indirect price when having to watch commercials—, they have to pay a state-imposed (publicly observable) license fee (denoted by f) whenever they own a TV set. Note that this specification also allows for the interpretation of the case where every household has to pay the license fee. In Germany, for example, this change is currently being discussed as the percentage of households owning a TV set is close to 100. Both interpretations imply that viewers have to incur the license fee even if they never watch the public-service broadcaster's program. The public-service broadcaster will receive parts of the fee according to its market share (see below). As mentioned in the introduction, there are different forms of public funding. Here, it is assumed that the public-service broadcaster may also show commercials during its program in order to generate revenues as this is very common across Europe.[14] Last, the public-service broadcaster has to offer the socially preferable type of program in return for public funding whereas the commercial station (subscript c) may choose between both types of programs, i.e. $s_c \in \{L, H\}$.
As the public-service broadcaster does not have a choice, let for simplification $\pi_p^{H|s_c} = \pi_p^{s_c}$ and $\pi_c^{s_c|H} = \pi_c^{s_c}$. Before turning to the equilibrium analysis the following assumptions are made:[15]

Assumption 2 $\tau_l \geq \frac{\tau_h}{2}$.

This assumption is made for convenience as it facilitates the derivation of the upper bound for f as well as the lower and upper bounds for β below.

Assumption 3 $f \leq \frac{3r}{2\gamma((1-\alpha)\tau_l + \alpha\tau_h)} \equiv f^{\max}$.

[14]See EUROPEAN BROADCASTING UNION (2006).

[15]Again, for a derivation of the bounds to follow, see the appendix.

This assumption ensures that the public station's advertising levels are positive.

Assumption 4 *If* $\alpha \leq \frac{1}{2}$*, then* $\beta^{\min,f}_{\alpha\leq\frac{1}{2}} \equiv$ $\equiv \max\{0, \frac{r(-(2-\alpha)\tau_l-(1+\alpha)\tau_h)+2\gamma f\tau_l\tau_h}{(1-2\alpha)r\tau_l\tau_h}, \frac{r(-2(2-\alpha)\tau_l+(1-2\alpha)\tau_h)+\gamma f\tau_l\tau_h}{(5-4\alpha)r\tau_l\tau_h}\} \leq \beta \leq$ $\leq \min\{\frac{r(-(1-2\alpha)\tau_l+2(2-\alpha)\tau_h)+\gamma f\tau_l\tau_h}{(5-4\alpha)r\tau_l\tau_h}, \frac{r((1-2\alpha)\tau_l+2(1+\alpha)\tau_h)-\gamma f\tau_l\tau_h}{(1+4\alpha)r\tau_l\tau_h}\} \equiv \beta^{\max,f}_{\alpha\leq\frac{1}{2}}$*. If* $\alpha > \frac{1}{2}$*, then* $\beta^{\min,f}_{\alpha>\frac{1}{2}} \equiv \max\{0, \frac{r(-(2-\alpha)\tau_l-2(1+\alpha)\tau_h)+2\gamma f\tau_l\tau_h}{(2\alpha-1)r\tau_l\tau_h}, \frac{r(-2(1+\alpha)\tau_l+(2\alpha-1)\tau_h)-\gamma f\tau_l\tau_h}{(1+4\alpha)r\tau_l\tau_h}\} \leq$ $\beta \leq \min\{\frac{r((2-\alpha)\tau_l+(1+\alpha)\tau_h)-2\gamma f\tau_l\tau_h}{(2\alpha-1)r\tau_l\tau_h}, \frac{r((1-2\alpha)\tau_l+2(1+\alpha)\tau_h)-\gamma f\tau_l\tau_h}{(1+4\alpha)r\tau_l\tau_h}\} \equiv \beta^{\max,f}_{\alpha>\frac{1}{2}}$.

This assumption ensures that advertising levels are positive and that market shares do not exceed 1.[16]
In the following the two possible cases where the commercial channel either shows the socially less preferable type of program or the socially preferable one are considered.

Commercial channel shows program L

Suppose first that the commercial station opts for the socially less preferable program. In this case the indifferent viewer from the first group can be determined by solving

$$\beta_l - \gamma a_p^L - f - \frac{1}{\tau_h} v_p^{I,L} = \beta_h - \gamma a_c^L - f - \frac{1}{\tau_l}\left(1 - v_p^{I,L}\right)$$

for $v_p^{I,L}$:

$$v_p^{I,L} = \frac{\tau_h(1 - \gamma\tau_l(a_p^L - a_c^L) - \beta\tau_l)}{\tau_l + \tau_h}. \tag{16}$$

Similarly, one gets

$$v_p^{II,L} = \frac{\tau_l(1 - \gamma\tau_h(a_p^L - a_c^L) + \beta\tau_h)}{\tau_l + \tau_h}. \tag{17}$$

Profits can then be written as

$$\pi_p^L = \left(a_p^L r + f\right)\alpha\frac{\tau_h(1 - \gamma\tau_l(a_p^L - a_c^L) - \beta\tau_l)}{\tau_l + \tau_h} + \\ + \left(a_p^L r + f\right)(1-\alpha)\frac{\tau_l(1 - \gamma\tau_h(a_p^L - a_c^L) + \beta\tau_h)}{\tau_l + \tau_h} \tag{18}$$

[16] Again, note that this assumption is not as restrictive as it may seem.

and

$$\pi_c^L = a_c^L r\alpha \left(1 - \frac{\tau_h(1-\gamma\tau_l(a_p^L - a_c^L) - \beta\tau_l)}{\tau_l + \tau_h}\right) + \\ + a_c^L r\,(1-\alpha)\left(1 - \frac{\tau_l(1-\gamma\tau_h(a_p^L - a_c^L) + \beta\tau_h)}{\tau_l + \tau_h}\right). \quad (19)$$

It is assumed that the public-service broadcaster—just like its commercial counterpart—maximizes profits. This can be explained by pointing out that managers are interested in maximizing their company's profit due to career concerns.[17] It is assumed that the public-service broadcaster does not get all of the revenues paid by viewers in order to get incentives right and because the state will use additional revenues for other purposes. Note that the results to be derived do not depend qualitatively on the this assumption as one might instead think of a situation where there are three broadcasting companies—two of which are public—that compete with each other on a circular city à la SALOP (1979). Then, revenues from levying f would have to be shared by both public broadcasting companies as well. This may be done according to their market performance.

The present setup comprises different possibilities of public funding. It may also reflect a regime where the public-service broadcaster receives a tax-funded government grant g instead of the license fee. More generally, a public-service broadcaster could get overall payments of $t = g + f$ net of advertising revenues which would not change the outcomes qualitatively either. The important feature is that payments are related to market performance. Maximizing profits with respect to advertising levels yields the following equilibrium levels:

$$a_p^L = \frac{(2-\alpha)\tau_l + (1+\alpha)\tau_h + (1-2\alpha)\beta\tau_l\tau_h}{3\gamma\tau_l\tau_h} - \frac{2f}{3r} \quad (20)$$

and

$$a_c^L = \frac{(1+\alpha)\tau_l + (2-\alpha)\tau_h - (1-2\alpha)\beta\tau_l\tau_h}{3\gamma\tau_l\tau_h} - \frac{f}{3r}. \quad (21)$$

[17]This assumption does not seem to be ill-founded as can be seen from a statement of the EUROPEAN COMMISSION concerning the above-mentioned ruling on the Danish public-service broadcaster TV2: "(...) the Commission's investigation did not produce evidence that TV2 had chosen not to maximise its advertising revenues." (see EUROPEAN COMMISSION, *TV2*, *supra* 3, at 1). See also KOHLSCHEIN (2005).

These advertising levels imply market shares of

$$v_p^{I,L} = \frac{r(-\tau_l(1-2\alpha) + 2(2-\alpha)\tau_h - (5-4\alpha)\beta\tau_l\tau_h) + \gamma\tau_l\tau_h f}{3r(\tau_l+\tau_h)} \tag{22}$$

and

$$v_p^{II,L} = \frac{r(2(1+\alpha)\tau_l + (1-2\alpha)\tau_h + (1+4\alpha)\beta\tau_l\tau_h) + \gamma\tau_l\tau_h f}{3r(\tau_l+\tau_h)}. \tag{23}$$

Here, an interesting side effect of the analysis arises: It helps explain certain real-life phenomena with respect to market shares. While Kohlschein (2005)'s model suggests that the public-service broadcaster always has a larger market share than the commercial one due to a lower advertising level, this is not necessarily the case in the present analysis. Here, the public-service broadcaster may indeed have a lower or higher share of the market. This is true whenever both stations show different program types and it reflects observations in real markets. For example, data for the German broadcasting market point out that the largest public-service broadcaster, the Arbeitsgemeinschaft der öffentlich-rechtlichen Rundfunkanstalten der Bundesrepublik Deutschland (ARD), and the largest commercial station, RTL Television, take turns with respect to market leadership.
Profits then amount to

$$\pi_p^L = \frac{(r((2-\alpha)\tau_l + (1+\alpha)\tau_h + (1-2\alpha)\beta\tau_l\tau_h) + \gamma\tau_l\tau_h f)^2}{9r\gamma\tau_l\tau_h(\tau_l+\tau_h)} \tag{24}$$

and

$$\pi_c^L = \frac{(r((1+\alpha)\tau_l + \tau_h(2-\alpha) - (1-2\alpha)\beta\tau_l\tau_h) - \gamma\tau_l\tau_h f)^2}{9r\gamma\tau_l\tau_h(\tau_l+\tau_h)}. \tag{25}$$

Commercial channel shows program H

Suppose now that the commercial broadcaster also shows the socially preferable type of program. Then, equilibrium advertising levels are given by

$$a_p^H = \frac{1}{\gamma((1-\alpha)\tau_l + \alpha\tau_h)} - \frac{2f}{3r} \tag{26}$$

and

$$a_c^H = \frac{1}{\gamma((1-\alpha)\tau_l + \alpha\tau_h)} - \frac{f}{3r}. \tag{27}$$

Viewer market shares for the two groups thus amount to

$$v_p^{I,H} = \frac{1}{2} + \frac{\gamma\tau_h f}{6r} \tag{28}$$

and

$$v_p^{II,H} = \frac{1}{2} + \frac{\gamma\tau_l f}{6r}. \tag{29}$$

Finally, profits are

$$\pi_p^H = \frac{(3r + \gamma f((1-\alpha)\tau_l + \alpha\tau_h))^2}{18r\gamma((1-\alpha)\tau_l + \alpha\tau_h)} \tag{30}$$

and

$$\pi_c^H = \frac{(3r - \gamma f((1-\alpha)\tau_l + \alpha\tau_h))^2}{18r\gamma((1-\alpha)\tau_l + \alpha\tau_h)}. \tag{31}$$

Before turning to the comparison of profits, a note on the effects of the license fee is in order. The license fee leads to a reduction in both stations' equilibrium advertising levels. More precisely, from equations (21) and (27) it is obvious that increasing the public fee leads to the same change in advertising levels ($-\frac{1}{3r}$) independent of whether the commercial channel opts for the socially preferable type of program or not. However, the public-service broadcaster's level is lowered to a larger extent—as was also shown by Kohlschein (2005). This is due to the fact that the revenues from the license fee are important to the public-service broadcaster too. This means that it tries harder to avoid a decrease in potential viewers' utility from being exposed to commercials thus increasing its market share. Therefore, the commercial channel always loses due to the license fee. However, in the present setup, there is a second aspect which has to do with the existence of different groups of viewers in the market and their different preferences. The competitive pressure which is captured by a lower advertising level affects market shares in the two viewer groups differently: $\frac{\partial v_p^{I,L}}{\partial f} = \frac{\partial v_p^{II,L}}{\partial f} = \frac{\gamma\tau_l\tau_h}{3r(\tau_l+\tau_h)}$, $\frac{\partial v_p^{I,H}}{\partial f} = \frac{\gamma\tau_h}{6r}$, $\frac{\partial v_p^{II,H}}{\partial f} = \frac{\gamma\tau_l}{6r}$. Comparing these derivatives, one gets $\frac{\partial v_p^{I,L}}{\partial f} < \frac{\partial v_p^{I,H}}{\partial f}$ as $\frac{\gamma\tau_l\tau_h}{3r(\tau_l+\tau_h)} < \frac{\gamma\tau_h}{6r} \Leftrightarrow \tau_l < \tau_h$ and $\frac{\partial v_p^{II,L}}{\partial f} > \frac{\partial v_p^{II,H}}{\partial f}$ as $\frac{\gamma\tau_l\tau_h}{3r(\tau_l+\tau_h)} > \frac{\gamma\tau_l}{6r} \Leftrightarrow \tau_h > \tau_l$. Thus, the decrease in market share for the commercial broadcaster when switching from the socially less preferable to the socially preferable type of

program is stronger for those viewers who prefer watching the socially less preferable type of program.
Given the profits for the commercial station's different programming choices, it is now possible to evaluate whether it is more likely to choose the socially preferable type of program than without public funding.

Comparison of profits

Consider first the case where the majority of viewers is interested in the socially less preferable type of program. Then, one arrives at the following result:

Lemma 4 If $\alpha > \frac{1}{2}$, then $\pi_c^H - \pi_c^L < 0$.

Proof See the appendix. ■

For the commercial station, this means that—just like in a situation without public funding (see *Lemma 3*)—showing the socially less preferable type of program is more profitable under public funding if the majority of viewers indeed has a preference for this type of program. Clearly, this means that the commercial broadcaster never opts for the socially preferable type of program as its incentives are not (sufficiently[18]) enhanced. However, public funding ensures that at least the public-service broadcaster shows the socially desirable type of program. Hence, there is an improvement for the case where the share of viewers more interested in the socially less preferable type of program is large.
Consider now a situation where the viewers preferring the socially desirable type of program are the majority. Comparing the incentives of the commercial station to show this program type yields:

Lemma 5 If $\alpha \leq \frac{1}{2}$, there are parameter values where $\pi_c^H - \pi_c^L > \pi_i^{H|L} - \pi_i^L$.

Unfortunately, a clearcut formal analysis is not tractable. Therefore, a numerical example is presented here to show that there are indeed regions of parameters for which the above lemma holds. To this end let $\beta = r = \gamma = f = 1$, $\alpha = 0$, $\tau_l = 0.095$, and $\tau_h = 0.12$. Advertising levels, viewer market shares, and profits are then approximately given by:

[18]Note that the difference may indeed become smaller.

a_i^L	$v_i^{II,L}$	π_i^L	$a_i^{H\|L}$	$v_i^{II,H\|L}$	$\pi_i^{H\|L}$	$\pi_i^{H\|L} - \pi_i^L$
8.33333	0.5	4.16667	9.39766	0.50171	4.68280	0.516**13**
a_c^L	$v_c^{II,L}$	π_c^L	a_c^H	$v_c^{II,H}$	π_c^H	$\pi_c^H - \pi_c^L$
9.12865	0.48403	4.41855	10.19298	0.48417	4.93510	0.516**55**

Table 2: Numerical example for *Lemma 5*

Further simulations reveal there is a tendency that $\pi_c^H - \pi_c^L > \pi_i^{H|L} - \pi_i^L$ is in particular more likely to hold if the number of viewers with a preference for the socially desirable type of program is high, if the breadths of appeal are not too far apart, and if the license fee is low.
A second comparison of the commercial broadcaster's incentives reveals the following:

Lemma 6 Let $\bar{f} \equiv \frac{2r(1-2\alpha)(\tau_h-\tau_l-2\tau_l\tau_h\beta)}{\gamma(\tau_h-\tau_l)(\tau_l-\alpha(\tau_l+\tau_h))}$. If $\alpha \leq \frac{1}{2}$ and $f \leq \min\{\bar{f}, f^{\max}\}$, then $\pi_i^H - \pi_i^{L|H} < \pi_c^H - \pi_c^L$.

Proof $\bar{f}$ can be easily derived by solving $\pi_i^H - \pi_i^{L|H} = \pi_c^H - \pi_c^L$ for f. ■

Note that in order to understand the implications of *Lemma 6*, one can distinguish between two cases depending on the relative strength of the breadths of appeal. First, if the breadths of appeal are not too different from each other (i.e. $\tau_l \to \tau_h$), then $\bar{f} < 0$ for $\beta > 0$. As mentioned above, the license fee decreases the commercial channel's advertising level by the same absolute amount independent of its programming choice. At the same time, the change in market share for both groups of viewers is the same too. However, given that profits are lower when choosing the socially less preferable type of program without public funding, then the license fee brings both profit levels closer together.[19]
If, on the other side, the breadths of appeal differ to a large extent (i.e. $\tau_l \ll \tau_h$), the effects are not as clearcut. Note that for $\tau_l < \frac{\alpha\tau_h}{1-\alpha} \Rightarrow \bar{f} \lesseqqgtr 0 \Leftrightarrow \beta \lesseqqgtr \frac{\tau_h-\tau_l}{2\tau_l\tau_h}$ as well as $\tau_l > \frac{\alpha\tau_h}{1-\alpha} \Rightarrow \bar{f} \lesseqqgtr 0 \Leftrightarrow \beta \gtreqqless \frac{\tau_h-\tau_l}{2\tau_l\tau_h}$. In order to illustrate the effects involved, consider the first case where $\tau_l < \frac{\alpha\tau_h}{1-\alpha}$. Then, on the one hand, the less intensive competition for those (majority) viewers preferring

[19]Assume, e.g., that the profit from opting for the socially less preferable type of program is close to zero. Then, the license fee cannot further decrease this profit level but will reduce the one associated with the socially preferable type of program.

to watch the socially preferable type of program makes this program type a more attractive option (competition effect). On the other hand, the fact that viewers face a much higher breadth of appeal when watching the less preferred type of program works in the opposite direction (breadth-of-appeal effect). As $\beta < \frac{\tau_h - \tau_l}{2\tau_l \tau_h}$ is more likely to hold, if the difference in the breadths of appeal becomes larger, the chance that the commercial broadcasting station chooses the same program type like the public-service broadcaster decreases compared to the benchmark case. In this case, it is more attractive to show the socially less preferable program as the majority of viewers considers it to have a much higher breadth of appeal even though it is not their preferred choice. If the opposite is true, the commercial channel would rather want to show the socially preferable type of program, i.e. the competition effect dominates such that the commercial channel prefers a less intense competition.
Hence, from the results given by *Lemmas 4–6*, one can derive the following proposition:

Proposition 2 *Suppose that $\alpha \leq \frac{1}{2}$. Then, under public funding the following changes obtain compared to the case without a license fee:*

(i) If $\pi_i^H - \pi_i^{L|H} < F < \pi_i^{H|L} - \pi_i^L$ and therefore $s_i = L \; \wedge \; s_j = H$ $\forall \, i, j \in \{1, 2\}$, $i \neq j$, then $s_c = H$ whenever $F < \pi_c^H - \pi_c^L$.

(ii) If $F > \pi_i^{H|L} - \pi_i^L$ and hence $s = L$, there are equilibria where $s_c = H$ as long as $\pi_i^{H|L} - \pi_i^L < F < \pi_c^H - \pi_c^L$.

This proposition thus clarifies the effects public funding has on a commercial channel's programming choice. There may be an improvement: Public funding can lead from a situation without any socially desirable type of program or different programming choices to programs of the socially preferable type only.

3 Conclusions

This paper analyzes the implications of public funding for a commercial station's incentives to show a socially preferable type of program given a public-service broadcaster has to provide such a program. The new approach here is the way program quality is defined: It is assumed that the types of programs available affect different groups of viewers differently. What is shown is that the introduction—or increase for that matter—of a license fee may indeed increase a commercial station's incentive to opt for this sort of program as well.

This is in contrast to the previously mentioned contribution by Armstrong (2005a). The analysis thus suggests that even if a commercial broadcaster and certain groups within society may be negatively affected by the existence of a license fee, it may benefit society as a whole through better programming choices. Therefore, there is no denying that public funding distorts competition and is bad news for some but there are also positive consequences with respect to programming choice associated with it. As was shown here, these consequences may be more than a sole reduction in advertising levels.

Another argument in favor of public funding is related to the practicability and efficiency of other means of regulation. As Doyle (1998) points out, license conditions in the United Kingdom require among others that channels' programming includes news, current affairs, local interest, and the like. However, the quality of such programs may not be defined and monitored without being subject to controversy. As a result a commercial station that offers a low-quality news program would still live up to the licensing standards. One may interpret the program type in the above model as being of high quality (socially preferable type) and of low quality (socially less preferable type). Then, a license fee may indeed help improve the quality of the program and thus avoid a situation where certain programs are only shown to please regulatory authorities at a low cost. As such public funding may be a suitable means to ensure the efficiency of other regulatory instruments. Hence, the analysis also helps explain why some commercial stations (e.g., in Germany) try to lure away well respected news anchormen from public-service broadcasters to establish a more serious image of their own news programs.

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Appendix

Derivation of lower and upper bounds for β without public funding (*Assumption 1*)

Proof Suppose that $\alpha \leq \frac{1}{2}$. Then, $a_1^{H|L} = \frac{(2-\alpha)\tau_l+(1+\alpha)\tau_h+(1-2\alpha)\beta\tau_l\tau_h}{3\gamma\tau_l\tau_h} \geq 0$ is always satisfied as the right-hand side of $\beta \geq -\frac{(2-\alpha)\tau_l+(1+\alpha)\tau_h}{(1-2\alpha)\tau_l\tau_h}$ is always negative. Now suppose that $\alpha > \frac{1}{2}$. From $a_1^{H|L} \geq 0 \Leftrightarrow \beta \leq \frac{(2-\alpha)\tau_l+(1+\alpha)\tau_h}{(2\alpha-1)\tau_l\tau_h} \equiv \bar{\beta}_1$. Proceeding in the same way for $a_2^{L|H} \geq 0$ reveals that for $\alpha \leq \frac{1}{2}$ $\beta \leq \frac{(1+\alpha)\tau_l+(2-\alpha)\tau_h}{(1-2\alpha)\tau_l\tau_h} \equiv \bar{\beta}_2$ must hold. Next, $v_1^{I,H|L} \geq 0 \Leftrightarrow \beta \leq \frac{-(1-2\alpha)\tau_l+2(2-\alpha)\tau_h}{(5-4\alpha)\tau_l\tau_h} \equiv \bar{\beta}_3$. Moreover, $v_1^{I,H|L} \leq 1$ must hold which implies $\beta \geq \frac{-2(2-\alpha)\tau_l+(1-2\alpha)\tau_h}{(5-4\alpha)\tau_l\tau_h} \equiv \beta_1$. Note that this condition is only relevant for $\alpha \leq \frac{1}{2}$ as $\beta_1 < 0$ otherwise. Similarly, $v_1^{II,H|L} \geq 0 \Leftrightarrow \beta \geq \frac{-2(1+\alpha)\tau_l-(1-2\alpha)\tau_h}{(1+4\alpha)\tau_l\tau_h} \equiv \beta_2$. Note that $\beta_2 > 0$ only holds for $\alpha > \frac{1}{2}$. Also, $v_1^{II,H|L} \leq 1 \Leftrightarrow \beta \leq \frac{(1-2\alpha)\tau_l+2(1+\alpha)\tau_h}{(1+4\alpha)\tau_l\tau_h} \equiv \bar{\beta}_4$. Comparing $\bar{\beta}_3$ and $\bar{\beta}_4$ shows that $\bar{\beta}_3 - \bar{\beta}_4 = -\frac{6(1-2\alpha)(\tau_l+\tau_h)}{(1+4\alpha)(5-4\alpha)\tau_l\tau_h} \lesseqgtr 0$ and hence $\bar{\beta}_3 \lesseqgtr \bar{\beta}_4 \Leftrightarrow \alpha \lesseqgtr \frac{1}{2}$. Now compare the candidates for the upper bounds. Suppose first that $\alpha \leq \frac{1}{2}$. Then, $\bar{\beta}_2 - \bar{\beta}_3 = \frac{3(2-\alpha)(\tau_l+\tau_h)}{(1-2\alpha)(5-4\alpha)\tau_l\tau_h} > 0$ and hence $\bar{\beta}_2 > \bar{\beta}_3$. If $\alpha > \frac{1}{2}$, $\bar{\beta}_1 - \bar{\beta}_4 = \frac{3(1+\alpha)(\tau_l+\tau_h)}{(2\alpha-1)(1+4\alpha)\tau_l\tau_h} > 0$ and hence $\bar{\beta}_1 > \bar{\beta}_4$. Last, it needs to be checked whether these upper bounds are always larger than the lower bounds for all values of α. Therefore, suppose first that $\alpha \leq \frac{1}{2}$. There, $\bar{\beta}_3 - \beta_1 = \frac{3(\tau_l+\tau_h)}{(5-4\alpha)\tau_l\tau_h} > 0$. If $\alpha > \frac{1}{2}$, then $\bar{\beta}_4 - \beta_2 = \frac{3(\tau_l+\tau_h)}{(1+4\alpha)\tau_l\tau_h} > 0$. Hence, one arrives at the lower and upper bounds put forward in *Assumption 1*. ■

Derivation of lower and upper bounds for β and an upper bound for f under public funding (*Assumption 2*)

Proof Note that $a_p^H \geq 0 \Leftrightarrow \bar{f}_1 \leq \frac{3r}{2\gamma((1-\alpha)\tau_l+\alpha\tau_h)}$, $v_p^{I,H} \leq 1 \Leftrightarrow \bar{f}_2 \leq \frac{3r}{\gamma\tau_h}$, $v_p^{II,H} \leq 1 \Leftrightarrow \bar{f}_3 \leq \frac{3r}{\gamma\tau_l}$, $\alpha \leq \frac{1}{2} \wedge \tau_l \leq \frac{\tau_h}{2} \Rightarrow \min\{\bar{f}_2, \bar{f}_1\}$, $\alpha \leq \frac{1}{2} \wedge \tau_l > \frac{\tau_h}{2} \Rightarrow \bar{f}_1$, $\alpha > \frac{1}{2} \Rightarrow \bar{f}_1$.
Suppose that $\alpha \leq \frac{1}{2}$. Proceeding in a similar way as above, $a_p^L \geq 0 \Rightarrow \beta \geq \frac{-r((2-\alpha)\tau_l+(1+\alpha)\tau_h)+2\gamma f\tau_l\tau_h)}{r\tau_l\tau_h(1-2\alpha)} \equiv \beta_1$. Moreover, $\alpha > \frac{1}{2} \Rightarrow \beta \leq \frac{r((2-\alpha)\tau_l+(1+\alpha)\tau_h)-2\gamma f\tau_l\tau_h)}{r\tau_l\tau_h(2\alpha-1)} \equiv \bar{\beta}_1$. ■

Proof of *Lemma 1*

Proof Let $F \equiv (\pi_i^{H|L} - \pi_i^L) - (\pi_i^H - \pi_i^{L|H})$. First consider the case where $\beta = 0$. In order to check if the continuous function F has a global maximum or minimum for $\alpha \in [0,\ 1]$, solve $\frac{\partial F}{\partial \alpha} = 0$ for α. The only (plausible) solution is $\alpha = \frac{1}{2}$. Since $0 < F(\alpha = 0) = F(\alpha = 1) = \frac{r(\tau_l - \tau_h)^2}{18\gamma\tau_h\tau_l} < F(\alpha = \frac{1}{2}) = \frac{r(\tau_l - \tau_h)^2}{2\gamma\tau_h\tau_l}$, F has a maximum if $\alpha = \frac{1}{2}$ and $\text{sgn}(F) > 0$ holds. Now consider an increase in β. Hence, $\frac{\partial F}{\partial \beta} = \frac{2r(1-2\alpha)^2(\tau_l - \tau_h + 2\beta\tau_l\tau_h)}{9\gamma(\tau_l + \tau_h)} \lesseqqgtr 0 \Leftrightarrow \beta \gtreqqless \frac{\tau_h - \tau_l}{2\tau_l\tau_h}$ which means that F has a maximum for $\beta = \frac{\tau_h - \tau_l}{2\tau_l\tau_h}$. This value is always lower than the maximum values specified in *Assumption 1.* Hence, it remains to be checked whether F may become negative if β reaches its maximally permissible values. Consider first the case where $\alpha \leq \frac{1}{2}$. There, solving $F(\beta = \beta^{\max}_{\alpha \leq \frac{1}{2}}) = 0$ for τ_l yields $\tau_l = \frac{(1 + 40\alpha^4 - 128\alpha^3 + 144\alpha^2 - 56\alpha \pm \sqrt{1 - 112\alpha - 1344\alpha^5 + 320\alpha^6 + 720\alpha^2 - 1824\alpha^3 + 2240\alpha^4})\tau_h}{4\alpha(-13 + 35\alpha - 32\alpha^2 + 10\alpha^3)}$. As $\tau_l < \tau_h$ must hold, it remains to be checked whether these expressions may indeed represent permissible nulls. First note that the term under the root is positive only if $0 \leq \alpha \lesssim 0.00949$. Also, setting the expression equal to 0 and solving for α reveals that there is no null. Last, the above expression for τ_l is negative for any $0 \leq \alpha \lesssim 0.00949$. Proceeding in the same way for $F(\beta = \beta^{\max}_{\alpha > \frac{1}{2}})$ yields the same results. ■

Proof of *Lemma 2*

Proof Let $F \equiv \pi_i^{H|L} - \pi_i^L$. Consider first the case where $\beta = 0$. Setting $F = 0$ and solving for τ_l yields $\tau_l = \frac{(1 + 4\alpha^3 - 6\alpha^2 + \sqrt{1 + 52\alpha^4 - 104\alpha^3 - 12\alpha^2 + 64\alpha})\tau_h}{4\alpha(4 + \alpha^2 - 4\alpha)}$. It needs to be checked whether this solution always satisfies the assumption that $\tau_l < \tau_h$. Differentiating the expression with respect to α gives an expression which has no extremum as it does not have a null for $\alpha > \frac{1}{2}$. Also, it is equal to $-\frac{4\tau_h}{3}$ for $\alpha = \frac{1}{2}$. Hence, the expression for τ_l is strictly decreasing in α and equal to τ_h for $\alpha = \frac{1}{2}$ as well as 0 for $\alpha = 1$. Now consider an increase in β. Hence, $\frac{\partial F}{\partial \beta} = \frac{2r\tau_l\tau_h(1-2\alpha)((2-\alpha)\tau_l + (1+\alpha)\tau_h + (1-2\alpha)\beta\tau_l\tau_h)}{9\gamma\tau_l\tau_h(\tau_l + \tau_h)}$. Suppose first that $\alpha \leq \frac{1}{2}$. Then solving $\frac{\partial F}{\partial \beta} \lesseqqgtr 0$ for β yields $\beta \lesseqqgtr -\frac{(2-\alpha)\tau_l + (1+\alpha)\tau_h}{(1-2\alpha)\tau_l\tau_h}$. As this expression is always negative, $\frac{\partial F}{\partial \beta} > 0$ must hold. Now assume that $\alpha > \frac{1}{2}$. There, $\frac{\partial F}{\partial \beta} \lesseqqgtr 0 \Leftrightarrow \beta \lesseqqgtr \frac{(2-\alpha)\tau_l + (1+\alpha)\tau_h}{(2\alpha - 1)\tau_l\tau_h}$. However, as this last condition is always larger than $\beta^{\max}_{\alpha > \frac{1}{2}}$, $\frac{\partial F}{\partial \beta} < 0$ must hold. Hence, F may only turn negative if $\alpha > \frac{1}{2}$. Now solve $F = 0$ for β which yields the above expression which can be shown to be decreasing in α. Moreover, $\frac{\partial F}{\partial \beta}$ is more likely to be positive the greater the difference in τ_l and τ_h. This is due to the fact that the lower bound for β converges to 0 if τ_l equals the expression from above. Note that β_0 may indeed take values which are permissible according to *Assumption 1.* This follows from the fact that $\lim_{\tau_l \to \tau_h} \beta_0 = 0$ whereas $\lim_{\tau_l \to \tau_h} \beta^{\max}_{\alpha > \frac{1}{2}} = \frac{3}{(1+4\alpha)\tau_h}$. At the same time, both β_0 and $\beta^{\max}_{\alpha > \frac{1}{2}}$ are increasing in τ_h for a given τ_l. As for a comparison with $\beta^{\min}_{\alpha > \frac{1}{2}}$, solve $\beta_0 - \beta^{\min}_{\alpha > \frac{1}{2}} = 0$

for τ_l. This yields $\tau_l = \frac{1-2\alpha^2+8\alpha+\sqrt{1+1296\alpha^6-1296\alpha^5+4\alpha^4-32\alpha^3+60\alpha^2+16\alpha}}{36\alpha^3}$. Inserting this expression back into the lower bound for β reveals that $\beta^{\min}_{\alpha>\frac{1}{2}} \leq 0$. Hence, as long as $\beta \leq \beta_0 \leq \beta^{\max}_{\alpha>\frac{1}{2}} \Rightarrow F \geq 0$. ■

Proof of *Lemma 4*

Proof Let $F \equiv \pi_c^H - \pi_c^L$. Now set $F = 0$ and solve for f. There are two solutions which both turn out not to be compatible with the assumption that $0 \leq f \leq f^{\max}$. ■