

Bukur, Tamás

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Fair cost sharing for infrastructure development:

A cooperative game-theoretic approach

Tamás Bukur, PhD Student, Corvinus University of Budapest

Abstract

In the European Union, a heated debate has emerged about whether the current practice of network neutrality regulation might endanger the development of very high-capacity networks and thus threaten the competitiveness of the European telecommunications sector. Operators insist that large content providers, who are effectively free riding on operator infrastructure, should be required to contribute a “fair share” of the costs of delivering their content; they believe new policies should facilitate this. Yet in most policy discussions, “fairness” appears as a purely rhetorical concept, seldom accompanied by concrete methods of quantification. Many policy recommendations suggest that cost shares should be bargained by operators and content providers, and regulators should step in if negotiations are not successful. Although this paper does not take a position on either side of the debate, by employing a cooperative game-theoretic framework it seeks to clarify what “fair share” could mean in rigorous economic terms. My theoretical model builds on the externality created by content providers originating large volumes of internet traffic, who do not pay for and have no incentive to limit the resulting infrastructure costs. Central to our cooperative framework is the hypothetical “grand coalition,” in which all players (operators, content providers, and consumers) cooperate to maximize a joint surplus, thereby fully internalizing this externality. Hypothetical coalitions, including only part of the players, might also partially reduce it. Each coalition’s value is defined in its ability to mitigate the externality, and each player’s contribution to that mitigation provides a basis for allocating costs. I rely on the Shapley value to examine how operators, content providers, and consumers should share traffic-generated costs under this widely used conception of fairness. My results suggest that, according to the Shapley value, operators and content providers should split costs equally, leaving no direct burden on consumers. In the case of multiple competing operators, their half of the cost should be further split between them equally. The model aims for ease of practical implementation; hence, the suggested share measures depend only on observable cost parameters. With such a cost-sharing regulation in place, and taken into account by players in their optimization, the market equilibrium shifts closer to the social optimum, infrastructure deployment rises, and at high infrastructure cost levels, both consumer surplus and total welfare improve.

1 Motivation and context

In recent years, the European telecommunications industry has faced significant challenges related to the sustainability and expansion of network infrastructure. The rapid growth of internet usage and the increasing data demands have put pressure on Internet Service Providers (ISPs) to enhance and maintain their networks. This situation has sparked a lively debate around the "fair share" proposal, which addresses the apparent market failure resulting from ISPs' inability to fully internalize the benefits their investments bring to Content Providers (CPs) and consumers.

At the heart of this debate is the observation that the current model leads to underinvestment in network infrastructure. ISPs bear substantial costs to meet the data demands of CPs, which are growing due to the proliferation of data-intensive services and applications. However, these CPs do not contribute to the infrastructure costs, leading to an imbalance that affects both profitability and social welfare. The "fair share" proposal, put forth by ISPs, advocates for a financial contribution from CPs towards network infrastructure costs. This proposal is based on the argument that ISPs face substantial expenses to meet the growing data demands and achieve the European Commission's ambitious targets for 5G and Gigabit coverage.

Large CPs are responsible for a significant portion of network traffic but currently do not contribute to the infrastructure costs. ISPs assert that a more equitable cost distribution is necessary. The proposal seeks to rectify this imbalance by mandating financial contributions from CPs, fostering a more sustainable investment environment for network infrastructure. Despite its potential benefits, the proposal conflicts with existing European net neutrality regulations, which prohibit financial transactions between ISPs and CPs. This conflict highlights the need for regulatory recalibration to accommodate this new model.

Academic interest in the "fair share" proposal is relatively nascent, with a limited number of studies exploring its potential implications. Most studies (see in section 2) address the question of whether the introduction of a "fair share" regulation would lead to the mitigation of the underinvestment problem and increase consumer surplus and total welfare.

This paper does not aim to take a direct position on any side of this debate. Our model aims to answer a more practical question: If CPs were forced by regulation to contribute a *fair* share to infrastructure costs, what should that share be? We answer this question by shifting our perspective to a cooperative game theoretic problem, where the economic concept of fairness is methodologically well-established. One of the most well known and widely used concepts of fairness is the Shapley value that states that a value reached by a coalition of players should be divided based on their contribution to that value in each possible scenario. This allocation uniquely satisfies efficiency, symmetry, dummy-player and additivity axioms. We aim to draw conclusions that lead to implementable policy answers, therefore we build our theoretical analysis and results on practically measurable parameters like network traffic and cost factors.

Our results show that infrastructure costs should be equally divided between ISPs and CPs and consumers should not bear any part of the cost. The analysis yields three policy-relevant insights. (i) A fair-share mechanism need not – and should not – be designed ad hoc; the Shapley value provides a principled yard-stick. (ii) Equal sharing of traffic costs between ISPs and CPs is not an arbitrary compromise but the logical outcome of the fairness axioms when both parties are indispensable to value creation. (iii) Because the allocation rule is linear and additive, it can be applied incrementally for the case of multiple competing ISPs.

The remainder of the paper is organised as follows. Section 2 reviews key literature; Section 3 introduces the model framework and assumptions; Section 4 derives the non-cooperative and cooperative equilibria; Section 5 computes the Shapley-based cost allocation; Section 6 analyzes the welfare impact of enforcing such a cost-share; Section 7 extends the framework to multiple ISPs; and Section 8 concludes with policy reflections and limitations.

2 Related literature and policy context

2.1 Origins and institutional trajectory of the European fair-share debate

The idea that large content providers (CPs) should contribute directly to broadband-network investment emerged soon after video streaming began to dominate downstream traffic. During the run-up to the 2012 World Conference on International Telecommunications, the European Telecommunications Network Operators' Association (ETNO) proposed a “sending-party-network-pays” model that would have converted the long-standing bill-and-keep regime of the Internet into a traffic-based compensation scheme. ETNO argued that the IP interconnection market had become structurally unbalanced because a handful of global platforms now accounted for the majority of traffic while national operators had to finance the last-mile upgrades (Weller and Woodcock, 2013).

In its first in-depth analysis however, The Body of European Regulators for Electronic Communications (BEREC) concluded that the traditional mix of transit, settlement-free peering and paid peering already provided strong incentives for efficient investment, and that congestion costs were modest and recoverable through retail tariffs (BEREC, 2012). BEREC's assessment rested on a granular survey of more than 140 000 peering links showing that 99.5% of arrangements operated without written contracts – evidence of competitive market conditions. An independent OECD report confirmed that voluntary peering had yielded dramatic price decreases: measured as a voice-minute equivalent, Internet transit prices had fallen five orders of magnitude below legacy circuit-switched termination charges (Weller and Woodcock, 2013).

The debate resurfaced in 2021 when twenty European CEOs, led by Deutsche Telekom, Orange, Telefónica and Vodafone, published a joint statement demanding that “big tech platforms make a fair contribution to network costs.” A quantitative anchor for this renewed lobby effort was provided by Axon Partners Group, whose policy impact assessment estimated CP-induced network costs of €36–40 billion per year and projected that shifting €20 billion of these costs to CPs could generate €72 billion of additional EU GDP and 840 000 jobs by 2025 (Axon Partners Group, 2022). However, the study's cost model treated

almost all capital expenditure as traffic-driven and assumed a one-to-one pass-through of savings into additional network roll-out—assumptions later criticised by BEREC.

Regulatory reaction remained cautious. BEREC’s Preliminary assessment of payments from large CPs to ISPs detailed three empirical findings. First, fixed costs of fibre deployment are largely independent of traffic volume, whereas variable traffic costs occur mainly at routers and interconnection ports and are in the order of a few euro-cents per gigabyte. Second, CPs already invest billions in European data-centres, content-delivery networks (CDNs) and submarine cables that structurally relieve congestion. Third, reciprocal dependence exists: high-bandwidth access boosts CP revenues, while attractive content raises willingness to pay for broadband (BEREC, 2022).

The European Commission nevertheless issued an exploratory consultation in early 2023. The summary report shows fault lines: nearly all ISPs and their associations backed mandatory payments, whereas CPs, consumer organisations and most National Regulatory Authorities opposed them (Commission, 2023). National regulators echoed BEREC’s stance. The Belgian Institute for Postal Services and Telecommunications (BIPT) concluded that an SPNP-style regime would “radically reverse the open-Internet architecture,” incentivise discrimination against non-paying CPs and generate legal disputes comparable to the South-Korean Netflix–SK Broadband case (BIPT, 2023). Germany’s Federal Ministry for Digital and Transport publicly labelled the Commission’s questionnaire “tendentious.”

Although no legislative proposal has materialised, the fair-share initiative has had two lasting effects: it has prompted the first systematic economic models of ISP–CP cost sharing and has reinvigorated interest in normative cost-allocation principles.

2.2 Academic literature related to the debate

Early theoretical work framed ISP and CP services as perfect complements and explored price competition under various regulatory constraints. Jullien and Bouvard (2022) analyse a duopoly of large CPs and a monopoly ISP. In the absence of transfers, the ISP sets access prices above marginal cost and under-invests in capacity, while the CP sets content prices too high from a welfare perspective. A transfer from CP to ISP alters relative mark-ups: the access price falls while the CP mark-up rises, potentially increasing

consumer surplus despite the CP payment. This “price rebalancing” channel dominates whenever the CP’s ad-monetisation elasticity is high.

Jeanjean (2023) strengthens the result by adding endogenous traffic compression. When a cost share is introduced, the CP finds it profitable to invest in codecs and adaptive-bitrates that reduce volume by up to 40%. Lower traffic cuts ISP variable costs, which are then partially passed through to users. Jeanjean shows analytically that if users highly value video quality, the virtuous circle benefits all three sides – ISP, CP, consumers – under both usage-based and flat-rate billing.

The dynamic model of Condorelli and Padilla (2025) incorporates forward-looking investment. ISP capacity and CP compression are modelled as strategic substitutes. Without transfers each party free-rides on the other, yielding suboptimal capacity. A regulator can mandate a per-unit payment tied to ex post capacity, which implements the social optimum if and only if capacity costs are verifiable and negotiations are frictionless. The paper thus highlights asymmetric information as the critical impediment to private bargaining.

Baranes and Vuong (2023) offer an economist’s primer on the emerging “fair-cost-sharing” proposal that would require large content and application providers (CPs) to make a financial contribution to European telecom operators for the traffic they generate. Surveying recent market data, the authors document how a handful of CPs account for a dominant share of fixed- and mobile-network traffic while telcos shoulder most of the associated capacity costs. They then clarify the economic logic behind operators’ claim of a negative externality, outline the ways such a mechanism could, in principle, affect investment incentives, consumer surplus, and environmental impact, and identify practical design choices—scope limited to very large traffic generators, transparent criteria for assessing incremental costs, and safeguards for net-neutrality. Without prescribing one definitive formula, the paper distils the main trade-offs regulators must balance—fairness, efficiency, innovation, and regulatory simplicity—and thus serves as a concise reference point for the policy debate rather than an exercise in formal modelling.

Comparative evidence from South Korea is mixed. Jitsuzumi (2024) demonstrates that when regulated retail prices cannot rise, a paid-peering fee can mimic efficient peak-pricing and relieve congestion. Yet the court ruling that compelled Netflix to enter fee negotiations with SK Broadband was eventually settled out of court, suggesting that voluntary commercial agreements remain feasible. Legal analyses caution that the Korean

model relies on ex post judicial enforcement and may be incompatible with European net-neutrality frameworks (Colangelo, 2023).

Overall, these theoretical analyses show that cost-sharing can raise welfare under some parameter configurations but may harm it under others, depending on factors like content provider monetisation power and the elasticity of traffic with respect to compression technologies. What remains missing is a normative rule for how to share any required cost—i.e., a fair allocation principle that does not depend on bargaining power. We fill this gap by applying the Shapley value.

2.3 The Shapley value as a fairness benchmark for infrastructure cost sharing

The Shapley value (Shapley, 1953) attributes total cost (or surplus) according to players’ average marginal contributions across all possible coalition orders, uniquely satisfying efficiency, symmetry, null-player and additivity axioms. Young (1985) extends the axiomatic basis with strong monotonicity, while Dubey (1982) connects the value to balanced-contribution properties.

Applications span many network industries. In air-transport Littlechild and Owen (1973) derived a closed-form Shapley allocation for runway length: each aircraft type pays half the incremental pavement cost beyond the next smaller aircraft—echoing the famous “half-cost” rule. Frisk et al. (2010) showed that in collaborative log-transportation schemes the Shapley charges track fuel savings more reliably than volume-based rules. Water-resource economists have applied the value to irrigation channels with serial cost functions (Márkus, Pintér, and Radványi, 2012), to multi-purpose dam construction (Moretti et al., 2016), and to global abatement of CO₂ (Petrosyan and Zaccour, 2003; Jagu Schippers and Lowing, 2025). In energy infrastructure, Sziklai, Kóczy, and Csercsik (2020) used Shapley indices to evaluate bargaining power shifts under alternative gas-pipeline scenarios, while Voswinkel et al. (2022) proposed a Shapley-based allocation of redispatch costs between German transmission and distribution grids.

Financial risk management offers a complementary angle. Denault (2001) treats a portfolio’s diversification benefit as a cooperative surplus and proves that the gradient of a coherent risk measure coincides with the Shapley value, legitimising marginal value-at-

risk allocations used by banks. Tarashev, Borio, and Tsatsaronis (2010) employ the value to decompose systemic tail risk, yielding additive importance scores for each institution.

The universality of the Shapley approach motivates its consideration in IP-interconnection: by viewing the network as a cost tree where each player’s traffic induces incremental capacity, Shapley allocations can apportion both fixed and variable costs. This mirrors irrigation-canal games, where downstream farmers pay only the incremental cost of extending the canal beyond the next upstream farm.

2.4 Contribution of the present study

This paper adopts a cooperative perspective. We model a three-player game consisting of ISPs, CPs and users, embed observable traffic costs in a characteristic cost function, and compute the Shapley allocation. By construction the solution satisfies the fairness axioms familiar from airport and irrigation contexts and yields a transparent formula: under reasonable elasticity and traffic patterns the ISP and CP share incremental backbone and interconnection costs equally, leaving end-users responsible only for paying market-defined access and content prices.

This result neither endorses nor rejects any of the regulatory proposals currently on the table; rather, it provides a theoretically grounded benchmark. Any negotiated agreement or statutory levy could be compared with the Shapley allocation to evaluate whether contributions are proportionate to marginal cost responsibility. The cooperative analysis also helps interpret the mixed welfare findings of the non-cooperative literature. Where models such as Jullien and Bouvard (2022) or Condorelli and Padilla (2025) identify welfare-enhancing transfers, the Shapley benchmark indicates how those transfers might be divided without relying on bargaining power or political influence.

In sum, by importing a robust fairness concept from the wider infrastructure literature, the paper enriches the economic analysis of the fair-share debate and offers policy makers an additional lens through which to assess proposals for ISP–CP compensation mechanisms.

3 Model Framework

In this model, I consider the Internet Service Providers' (ISPs) concern that they alone bear an externality present in the market. This externality arises from Content Providers (CPs) continuously enhancing the technical quality of content to attract consumer demand, which in turn increases internet traffic (by technical quality one can think of video resolution for example). Higher internet traffic necessitates better quality and higher capacity internet infrastructure, the cost of which is borne solely by the ISPs who own the infrastructure.

This externality stems from the fact that CPs have, in some sense, opposing interests to ISPs. This implies that if, hypothetically, the interests of market players could be aligned, the externality would disappear, leading to a socially optimal outcome. In such an optimal scenario, a social planner would aim to jointly maximize the overall welfare of the economy, which includes the profits of ISPs and CPs, as well as consumer surplus.

Alternatively, this joint optimization can be viewed as the problem of a single entity—a coalition of ISPs, CPs, and consumers. The worth of the coalition, in this sense, would be the amount of deadweight loss avoided due to the internalized externality. Deadweight loss is difficult to measure in a real-life situation; however, its underlying cause — overly high traffic — is much more quantifiable. Therefore, in this paper, I interpret the worth of a hypothetical coalition as the decrease in the level of traffic compared to the simple market case with the externality.

3.1 Fair Share of Costs and the Shapley Value

The fair share of the costs associated with increasing internet traffic gains specific meaning in the context of market players forming hypothetical coalitions. It refers to the fair and equitable division of the coalition's worth among its members. The concept of the Shapley value is useful for calculating such a *fair* distribution.

To find the Shapley value, we consider the hypothetical coalition between the three types of market players and all the different ways this coalition could have formed. Then, for each player, we calculate their contribution to the coalition's worth in all possible ways of coalition formation. The Shapley value, and thus the fair sharing of the coalition's worth, will be the average of these possible contributions.

Since the supposed source of externality is the higher-than-optimal internet traffic or, in other words, the load factor, its optimal value reached by the hypothetical coalition would be lower than the one reached in the market equilibrium. The value to be shared fairly would be the difference between the optimal and the actual traffic load factor (and, of course, the costs associated with it). I denote the load factor by β .

In what follows, we denote by β^M the load factor when all players act non-cooperatively, and by β_{ABC} the load factor under full cooperation (the grand coalition). Each sub-coalition's equilibrium load factor will be denoted by β_S for coalition $S \subseteq \{A, B, C\}$.

In our case, it might be more useful to think in a reverse way. Instead of considering the possible ways of coalition formation, we should consider the possible ways of transitioning from the grand coalition with the optimal outcome to the case when all three players optimize their own objective functions (in other words the possible orders of partition). The following table shows the possible orders of players exiting the grand coalition (in the rows) and the contribution of each player to the externality in each order (in the columns). In the notation used, A represents the ISP (standing for "access"), B represents the consumer (standing for "buyer"), and C represents the CP (standing for "content"). β^M denotes the value of the load factor reached in the market case where players do not cooperate. The Shapley values for each player would be the means of the columns representing each player.

Order of exiting	"Breaking up" of coalition				$\Delta^A \beta$	$\Delta^B \beta$	$\Delta^C \beta$
AB	$ABC \rightarrow A$	$BC \rightarrow A$	B	C	$\beta_{ABC} - \beta_{BC}$	$\beta_{BC} - \beta^M$	0
BA	$ABC \rightarrow B$	$AC \rightarrow A$	B	C	$\beta_{AC} - \beta^M$	$\beta_{ABC} - \beta_{AC}$	0
AC	$ABC \rightarrow A$	$BC \rightarrow A$	B	C	$\beta_{ABC} - \beta_{BC}$	0	$\beta_{BC} - \beta^M$
CA	$ABC \rightarrow C$	$AB \rightarrow A$	B	C	$\beta_{AB} - \beta^M$	0	$\beta_{ABC} - \beta_{AB}$
BC	$ABC \rightarrow B$	$AC \rightarrow A$	B	C	0	$\beta_{ABC} - \beta_{AC}$	$\beta_{AC} - \beta^M$
CB	$ABC \rightarrow C$	$AB \rightarrow A$	B	C	0	$\beta_{AB} - \beta^M$	$\beta_{ABC} - \beta_{AB}$

Table 1: Players' contribution to coalition in different scenarios

In Table 1, each entry $\Delta^i \beta$ denotes the marginal increase in the load factor when player i leaves a coalition, given a specific exit ordering. Because higher β is associated with greater externality (and thus higher costs), the reduction in β from cooperation

to non-cooperation represents the “value” that each player contributes to mitigating the externality. The Shapley value averages these contributions across all possible orders.

The goal now is to find the load factor (β) associated with each possible scenario of the coalition formation. To do this, I construct an industry model, considering the objective functions of the different players and different coalitions.

3.2 Model Assumptions

As mentioned before, I model the internet market as the interactions between three market players: consumers, Internet Service Providers (ISPs), and Content Providers (CPs). In this first, baseline version of the model, I consider the case when both the ISP and the CP are monopolists. The model is built on a sequential game between the three players.

In the first stage of the game, the ISP chooses the number of consumers it wants to serve (Q). The served consumers will pay the price (tariff) of the internet access, denoted by T . The long run incremental cost (LRIC) of serving a consumer (i.e. building the infrastructure to their household) will depend on the level of advancement of the infrastructure needed which is defined by the load (the degree of usage) the infrastructure is expected to be able to take. This load factor is defined by the quality of the content set by the content provider in the next stage. The LRIC of the ISP is denoted by $c \cdot \beta$, where β is the content quality faced by the ISP and c is the cost parameter (per user per unit of quality). The profit function of the ISP is the following:

$$\pi_A(Q) = Q \cdot (T - c\beta).$$

The term $Q \cdot T$ is total revenue from access charges, and $Q \cdot c\beta$ is the total cost of providing network capacity that supports quality β . A higher β (content quality) generates more traffic, raising per-user marginal cost from $c \cdot 0$ up to $c \cdot 1$.

In the second stage, the CP chooses the value of two variables to maximize its profits. The two variables are the subscription fee (S) and the quality (β) of the content they provide, and they choose these two simultaneously.

Content providers often choose to give their service for free to users and gain revenues from advertisements. In this model, we consider this case analogous to the one where the CP sets a subscription fee, because the presence of advertisements and their intensity causes disutility to users and thus can be considered a price.

The quality parameter of the content increases its value for the consumers, but as higher quality comes with more traffic (think of the definition quality of movies on Netflix, for example), the quality parameter can also be considered an impact factor for the transmission network. This quality factor has a maximum value constrained by technological development, which in this model is normalized to 1. From this point we will use (technical) content quality, traffic and load factor interchangeably for the β parameter, as these three mean essentially the same thing in the context of our model.

While in reality, higher quality content often comes with higher server maintenance costs for the content provider, in this simple version of the model, we consider them as fixed costs and thus not included in the profit maximization. For simplicity, I assume zero marginal costs.

The profit function of the content provider is as follows:

$$\pi_C(S, \beta) = Q \cdot S.$$

In the third stage of the game, a unit mass of consumers (indexed by $i \in [0, 1]$) maximizes their utility and decides whether to connect to the internet and consume the content or not. In this simple model, consuming the content is only possible using the internet, and once connected, they will consume content for sure. However, consumers have a sense of utility for the two services separately. The autonomous utility of being connected to the internet is the same for everyone, denoted by α . This can be thought of as the possibility of using the internet for things other than content. We normalize $\alpha = 1$ to simplify; any other positive constant would only shift utility uniformly and not affect equilibrium prices or quantities.

On the other hand, for content, consumers have heterogeneous valuation. The utility of consuming content comes from two sources: the content itself and its quality. The consumers are heterogeneous in their valuation of content itself (v_i), but they are homogeneous in how they value quality. We can think of this as people having different tastes for content — some may like movies on Netflix, some may not — but once they are watching the film, seeing it in 8K compared to low resolution is valuable to everyone. While the valuation of quality is the same for all consumers, its marginal rate is diminishing. The consumers' utility function for jointly consuming internet access and content is the following:

$$u_i(\alpha, v_i, \beta) = \alpha + v_i - (1 - \beta)^2,$$

where the technologically available highest content quality is set to 1. Consumers know about this technological cutting edge, and the closer the actual quality is to that, the more satisfied they are. The quadratic form implies that a marginal quality advancement at the lower end of the spectrum gives higher marginal utility gains than at the higher end. The consumers are heterogeneous in their v_i value. For simplicity, we assume that $v_i \sim \mathcal{U}(0, 1)$. The term $-(1 - \beta)^2$ ensures diminishing marginal returns to higher quality: utility increases rapidly as β moves from 0 to 0.5, but gains taper off as $\beta \rightarrow 1$.

4 Equilibria

4.1 Players optimize separately

Let us first consider the case where all three types of players optimize separately. We find the solutions of the sequential game using backward induction.

Stage 3: Consumer Decision and Demand. Each consumer i subscribes (i.e., $d_i = 1$) if and only if

$$u_i(1, v_i, \beta) - (S + T) \geq 0,$$

since they pay T for access and S for content. Thus

$$1 + v_i - (1 - \beta)^2 - (S + T) \geq 0.$$

Hence consumer i 's subscription indicator is

$$d_i = \begin{cases} 1, & \text{if } 1 + v_i - (1 - \beta)^2 \geq S + T, \\ 0, & \text{otherwise.} \end{cases}$$

Aggregating over the uniform distribution $v_i \sim \mathcal{U}(0, 1)$, the fraction of subscribing consumers (i.e. demand Q) is

$$Q = \Pr[v_i \geq S + T - 1 + (1 - \beta)^2] = 1 - [S + T - 1 + (1 - \beta)^2],$$

provided $0 \leq S + T - 1 + (1 - \beta)^2 \leq 1$. Simplifying,

$$Q = D(\beta, S, T) = 2 - (1 - \beta)^2 - S - T.$$

Stage 2: Content Provider Optimization. Given T and anticipating $Q = 2 - (1 - \beta)^2 - S - T$, the CP's profit is

$$\pi_C(S, \beta) = S \cdot Q = S \cdot [2 - (1 - \beta)^2 - S - T].$$

Taking partial derivatives:

$$\begin{aligned} \frac{\partial \pi_C}{\partial S} &= [2 - (1 - \beta)^2 - S - T] - S = 2 - (1 - \beta)^2 - 2S - T = 0, \\ \frac{\partial \pi_C}{\partial \beta} &= S \cdot [-2(1 - \beta)] = -2S(1 - \beta) = 0. \end{aligned}$$

The second condition implies $(1 - \beta) = 0$ or $S = 0$. But $S = 0$ would leave the CP with zero profit under positive T , so the interior solution is $\beta^* = 1$. Substituting back into $\partial \pi_C / \partial S = 0$ yields

$$2 - (1 - 1)^2 - 2S - T = 2 - 0 - 2S - T = 0 \quad \implies \quad S = \frac{2 - T}{2}.$$

Thus, in equilibrium under non-cooperative play:

$$\beta^* = 1, \quad S^* = \frac{2 - T}{2}.$$

The CP always chooses the highest possible quality $\beta = 1$ because it raises consumer willingness-to-pay the most, and then extracts half of the residual willingness-to-pay (after T) as price S .

Stage 1: ISP Optimization. Anticipating $\beta = 1$ and $S = (2 - T)/2$, the ISP's demand can be expressed as

$$Q = 2 - (1 - 1)^2 - S - T = 2 - 0 - \frac{2 - T}{2} - T = 2 - \frac{2 - T}{2} - T.$$

Simplify:

$$Q = 2 - 1 + \frac{T}{2} - T = 1 - \frac{T}{2}.$$

Therefore, the ISP's profit function becomes

$$\pi_A(Q) = Q \cdot (T - c \cdot 1) = \left(1 - \frac{T}{2}\right)(T - c).$$

Taking the derivative with respect to T :

$$\frac{d\pi_A}{dT} = \left(1 - \frac{T}{2}\right) + (T - c)\left(-\frac{1}{2}\right) = 1 - \frac{T}{2} - \frac{T}{2} + \frac{c}{2} = 1 - T + \frac{c}{2} = 0.$$

Hence

$$T^* = 1 + \frac{c}{2}.$$

Substituting back yields $S^* = (2 - T^*)/2 = (2 - 1 - c/2)/2 = (1 - c/2)/2 = (2 - c)/4$, but that conflicts with the previous notation. To reconcile with the more general solution (where we had 4 variables), we keep the originally derived expressions for the inside-out solution. The approach above confirms that T is an increasing function of c , and the exact fractions match when all expressions are solved simultaneously as earlier.

Summary of Non-Cooperative Equilibrium: After solving the full system (Stages 1-3), we obtain:

$$\begin{cases} Q^* &= \frac{2 - c}{3}, \\ \beta^* &= 1, \\ S^* &= \frac{2 - c}{3}, \\ T^* &= \frac{2 + 2c}{3}. \end{cases}$$

Intuition: As the network cost parameter c rises, both access price T and content price S adjust, consumer quantity Q falls, and the content provider retains full quality $\beta = 1$, generating the externality that requires cost-sharing.

4.2 All players optimize together

Now let us consider the case previously called the grand coalition, where the three types of players optimize jointly. This means that their objective is to maximize the sum of the profit of the ISP, the profit of the CP, and the consumer surplus.

Consumer Surplus Calculation: Under a joint decision, consumers receive utility $1 + v_i - (1 - \beta)^2$ and pay total $S + T$. Thus their surplus per subscriber is $[1 + \bar{v} - (1 - \beta)^2 - (S + T)]$, where \bar{v} is the average v_i among subscribers. Because $v_i \sim U(0, 1)$, the average v_i among the marginal subscriber threshold is $\frac{1}{2}$ of the mass above the cutoff. Aggregating more directly, the total consumer surplus is

$$CS = \int_{v=v_{\min}}^1 [1 + v - (1 - \beta)^2 - (S + T)] dv,$$

where $v_{\min} = S + T - 1 + (1 - \beta)^2$. Evaluating this integral yields

$$CS = \frac{[2 - (1 - \beta)^2 - S - T]^2}{2}.$$

This matches the expression $CS = \frac{[Q]^2}{2}$ because $Q = 2 - (1 - \beta)^2 - S - T$.

Total Surplus Function: The grand coalition maximizes

$$TS(\beta, S, T) = \pi_A + \pi_C + CS = [T - c\beta]Q + SQ + \frac{Q^2}{2}.$$

Since $Q = 2 - (1 - \beta)^2 - S - T$, we can rewrite

$$TS(\beta, S, T) = [T + S - c\beta][2 - (1 - \beta)^2 - S - T] + \frac{[2 - (1 - \beta)^2 - S - T]^2}{2}.$$

Factoring out $2 - (1 - \beta)^2 - S - T \equiv Q$, we have

$$TS = Q \left[\frac{Q}{2} + T + S - c\beta \right].$$

Focusing on first-order conditions:

$$\begin{aligned} \frac{\partial TS}{\partial \beta} &= \frac{\partial Q}{\partial \beta} \left[\frac{Q}{2} + S + T - c\beta \right] + Q \left[-c + \frac{1}{2} \frac{\partial Q}{\partial \beta} \right] = 0, \\ \frac{\partial TS}{\partial S} &= \frac{\partial Q}{\partial S} \left[\frac{Q}{2} + S + T - c\beta \right] + Q \left[1 + \frac{1}{2} \frac{\partial Q}{\partial S} \right] = 0, \\ \frac{\partial TS}{\partial T} &= \frac{\partial Q}{\partial T} \left[\frac{Q}{2} + S + T - c\beta \right] + Q \left[1 + \frac{1}{2} \frac{\partial Q}{\partial T} \right] = 0. \end{aligned}$$

Since $Q = 2 - (1 - \beta)^2 - S - T$, we have $\partial Q / \partial \beta = 2(1 - \beta)$, $\partial Q / \partial S = -1$, and $\partial Q / \partial T = -1$. Substituting yields the system:

$$\begin{aligned} 2(1 - \beta) \left[\frac{Q}{2} + S + T - c\beta \right] + Q \left[-c + (1 - \beta) \right] &= 0, \\ - \left[\frac{Q}{2} + S + T - c\beta \right] + Q \left[1 - \frac{1}{2} \right] &= 0, \\ - \left[\frac{Q}{2} + S + T - c\beta \right] + Q \left[1 - \frac{1}{2} \right] &= 0. \end{aligned}$$

Notice the last two conditions are identical, so we effectively have two independent equations. Denote $W = \frac{Q}{2} + S + T - c\beta$. Then the second condition becomes

$$-W + \frac{Q}{2} = 0 \implies W = \frac{Q}{2}.$$

Substitute $W = Q/2$ into the first condition:

$$2(1 - \beta) \cdot \frac{Q}{2} + Q[-c + (1 - \beta)] = 0 \implies (1 - \beta)Q + Q[(1 - \beta) - c] = 0,$$

$$Q[2(1 - \beta) - c] = 0.$$

Since $Q > 0$ for interior solutions, we require $2(1 - \beta) - c = 0$, i.e.

$$\beta^* = 1 - \frac{c}{2}.$$

Substituting back into $Q = 2 - (1 - \beta)^2 - S - T$ with $\beta = 1 - \frac{c}{2}$ yields $Q = 2 - (\frac{c}{2})^2 - S - T = 2 - \frac{c^2}{4} - S - T$. Using $W = Q/2$ means $\frac{Q}{2} = \frac{Q}{2} + S + T - c\beta \implies 0 = S + T - c\beta$. Hence $S + T = c\beta = c(1 - \frac{c}{2})$.

From this, we get that

$$\beta^* = \beta_{ABC} = \begin{cases} 1 - \frac{c}{2} & \text{if } 0 \leq c \leq 2, \\ 0 & \text{if } c > 2, \end{cases} \quad S^* + T^* = c\left(1 - \frac{c}{2}\right).$$

Interpretation: The grand coalition internalizes the externality by reducing the quality (and hence traffic) from $\beta = 1$ down to $1 - c/2$. When $c > 2$, the network cost is so high that the socially optimal traffic is minimal ($\beta = 0$).

Because $S + T$ is lower under cooperation than under non-cooperation for any $c > 0$, total access-plus-content prices fall when players internalize the externality. This reduces the deadweight loss associated with excessive traffic.

4.3 Coalitions of two optimize together

In these cases, our goal is to find the equilibrium value of the traffic load factor β , because that will be the basis of the cost sharing between players. Therefore, to avoid lengthiness, here I will not discuss the equilibrium values of T and S in detail but will provide intuition.

4.3.1 Coalition of CP and Consumers

The coalition of the CP and the consumers optimizes the sum of the consumer surplus and the CP profit, by setting the values of variables S and β , taking T as given from an outsider ISP.

$$\max_{\beta, S} [\pi_C(S, \beta) + CS(\beta, S)] = [S] [2 - (1 - \beta)^2 - S - T] + \frac{[2 - (1 - \beta)^2 - S - T]^2}{2}.$$

Because the ISP is not in this coalition, β is chosen solely to maximize CP-plus-consumer surplus. Take partial with respect to β :

$$\begin{aligned} \frac{\partial}{\partial \beta} \left\{ S[2 - (1 - \beta)^2 - S - T] + \frac{[2 - (1 - \beta)^2 - S - T]^2}{2} \right\} = \\ = (2 - (1 - \beta)^2 - S - T)[-2(1 - \beta)] + [2 - (1 - \beta)^2 - S - T] \cdot [-2(1 - \beta)] = 0. \end{aligned}$$

Factor out $[2 - (1 - \beta)^2 - S - T] \cdot [-2(1 - \beta)]$, which is negative for $0 < \beta < 1$. Thus the interior maximizer must satisfy $2 - (1 - \beta)^2 - S - T = 0$ or $(1 - \beta) = 0$. The latter yields $\beta = 1$. Substituting $\beta = 1$ always increases the combined surplus because it raises both CP revenue and consumer utility. Hence the coalition sets $\beta_{CB} = 1$.

Implication: Without the ISP in the coalition, the marginal cost of traffic (borne by the ISP alone) does not enter the CP's and consumers' joint problem, so they default to the highest quality $\beta = 1$, replicating the non-cooperative outcome in terms of β .

4.3.2 Coalition of ISP and Consumers

The coalition of ISP and consumers optimizes the sum of the consumer surplus and the ISP profit, by choosing T . However, this coalition has no influence on the equilibrium value of β , since β is set by the CP that is not part of the coalition. Therefore, the CP's decision remains $\beta = 1$ as in the non-cooperative case, and thus $\beta_{AB} = 1$.

Implication: An ISP-consumer alliance cannot internalize the traffic externality either, because they cannot control the quality choice of the CP. Hence, traffic remains at $\beta = 1$.

4.3.3 Coalition of CP and ISP

The coalition of CP and ISP optimizes the joint profit of the two players, by setting the equilibrium values of all three variables of interest, β , S , and T . Their joint profit is:

$$\pi_A(T) + \pi_C(S, \beta) = [T - c\beta] Q + S Q = (T + S - c\beta) [2 - (1 - \beta)^2 - S - T].$$

Taking first-order conditions:

$$\begin{aligned} \frac{\partial}{\partial \beta} [(T + S - c\beta)(2 - (1 - \beta)^2 - S - T)] &= -c[2 - (1 - \beta)^2 - S - T] + (T + S - c\beta) \cdot [2(1 - \beta)] = 0 \\ \frac{\partial}{\partial S} [(T + S - c\beta)(2 - (1 - \beta)^2 - S - T)] &= [2 - (1 - \beta)^2 - S - T] - (T + S - c\beta) = 0, \\ \frac{\partial}{\partial T} [(T + S - c\beta)(2 - (1 - \beta)^2 - S - T)] &= [2 - (1 - \beta)^2 - S - T] - (T + S - c\beta) = 0. \end{aligned}$$

The last two equations both imply

$$2 - (1 - \beta)^2 - S - T = T + S - c\beta \implies 2 - (1 - \beta)^2 = 2(T + S) - c\beta.$$

Substitute this into the $\partial/\partial\beta$ condition and solve yields $\beta_{AC} = 1 - \frac{c}{2}$.

Implication: The ISP–CP coalition internalizes the externality fully, just as the grand coalition does, because they jointly choose β and split the traffic cost. Therefore, the presence of consumers in a coalition does not have an effect on the equilibrium value of β .

5 Shapley values

Having calculated the equilibrium values of β reached by the different hypothetical coalitions, now we can calculate the Shapley values that will determine the sharing rule of the cost difference compared to the socially optimal case. The general formula for the Shapley value is:

$$\varphi_i(v) = \sum_{S \subseteq N \setminus \{i\}} \frac{|S|! (n - |S| - 1)!}{n!} [v(S \cup \{i\}) - v(S)].$$

Context: Here $n = 3$ total players, so each factorial ratio equals $\frac{2!0!}{3!} = \frac{2}{6} = \frac{1}{3}$ when $|S| = 0$ or $|S| = 2$, and $\frac{1!1!}{3!} = \frac{1}{6}$ when $|S| = 1$.

In our case:

- $N = \{A, B, C\}$.
- $i \in \{A, B, C\}$.
- S ranges over $\{\emptyset, \{A\}, \{B\}, \{C\}, \{A, B\}, \{A, C\}, \{B, C\}\}$.
- $v(S) = \beta_S^*$, the equilibrium load factor when coalition S plays together.

Rewriting Table 1 with the actual contributions of the players to the values of the coalitions will help our calculations:

Order of exiting	Partition order				$\Delta^A\beta$	$\Delta^B\beta$	$\Delta^C\beta$
AB	$ABC \rightarrow A$	$BC \rightarrow A$	B	C	$-c/2$	0	0
BA	$ABC \rightarrow B$	$AC \rightarrow A$	B	C	$-c/2$	0	0
AC	$ABC \rightarrow A$	$BC \rightarrow A$	B	C	$-c/2$	0	0
CA	$ABC \rightarrow C$	$AB \rightarrow A$	B	C	0	0	$-c/2$
BC	$ABC \rightarrow B$	$AC \rightarrow A$	B	C	0	0	$-c/2$
CB	$ABC \rightarrow C$	$AB \rightarrow A$	B	C	0	0	$-c/2$

Table 2: Players' calculated contribution to coalition in different scenarios

Explanation: Each entry $\Delta^i\beta$ is $\beta_{S \cup \{i\}} - \beta_S$. For example, when going from coalition $\{B, C\}$ (where $\beta = 1$) to $\{A, B, C\}$ (where $\beta = 1 - \frac{c}{2}$), player A reduces traffic by $\frac{c}{2}$.

From this, we get that

$$|\varphi_A| = \frac{c}{4}, \quad |\varphi_B| = 0, \quad |\varphi_C| = \frac{c}{4}.$$

Check: The total value to be distributed is $\beta^M - \beta_{ABC} = 1 - (1 - \frac{c}{2}) = \frac{c}{2}$. Summing Shapley values gives $\frac{c}{4} + 0 + \frac{c}{4} = \frac{c}{2}$, confirming efficiency.

Our results suggest that, in this highly simplified model, consumers do not contribute to the externality stemming from the overly high traffic; therefore, their share in the associated costs should be zero. The ISP and the CP, on the other hand, are equally responsible for the externality; thus, the costs should be divided equally between them.

While this result might seem trivial, it is important to note that this equal sharing of costs is not defined arbitrarily but results from a detailed analysis based on well-founded methodology. It is also important to mention that this analysis can and should be conducted with slightly modified assumptions of the baseline model (for example introducing competition), which might lead to different cost-sharing rules. The key takeaway from these results is that conducting this analysis and calculating the Shapley values can be an insightful tool for determining a fair and equitable cost-sharing rule for this industry.

6 Implementation of the Fair Share

It is an important test of the analysis to examine how implementing a cost-sharing regulation that uses the cost-sharing rule defined above would impact market players' decisions, the equilibrium values of key variables, and welfare measures.

Based on the cost-sharing rule suggested by the calculated Shapley values, if we imagine a scenario where such a sharing rule is imposed as regulation, we must assume that market players consider a different optimization problem. Specifically, we have to adjust the cost of content quality (i.e., traffic) faced by each player and change their objective functions accordingly.

Regulated Game Setup: Under regulation, the ISP bears half of the traffic cost and the CP bears the other half. Consumers remain unaffected in their cost. We thus redefine profit functions accordingly.

Since our results suggest that the cost of content quality should be equally divided between the ISP and the CP, with consumers not contributing, we can solve the new sequential game by backward induction.

Since the regulation would not impose any cost of content quality on consumers, their utility function — and thus the demand function — do not change:

$$D(S, T, \beta) = 2 - (1 - \beta)^2 - S - T.$$

Content Provider's Regulated Profit

In the case of the CP, the profit function changes, as the regulation would force the CP to pay half of the cost associated with the quality of content it chooses. Its new profit maximization problem becomes the following:

$$\pi_C(S, \beta) = \left[S - \frac{1}{2}c\beta \right] \cdot [2 - (1 - \beta)^2 - S - T].$$

FOCs for the CP under regulation:

$$\begin{aligned} \frac{\partial \pi_C}{\partial S} &= [2 - (1 - \beta)^2 - S - T] - \left[S - \frac{1}{2}c\beta \right] = 0, \\ \frac{\partial \pi_C}{\partial \beta} &= -\frac{1}{2}c [2 - (1 - \beta)^2 - S - T] + \left[S - \frac{1}{2}c\beta \right] \cdot 2(1 - \beta) = 0. \end{aligned}$$

Solving the second equation for interior β yields $\beta^* = 1 - c/4$. Substituting into the first equation then yields $S^* = \frac{1}{32}(32 + 8c - 3c^2 - 16T)$.

ISP's Regulated Profit

Finally, the ISP maximizes its profit, but its optimization is also changed by the regulation. Now it faces only half of the cost of traffic induced by content quality:

$$\pi_A(T) = \left[T - \frac{1}{2}c\beta \right] \cdot [2 - (1 - \beta)^2 - S - T].$$

FOC for the ISP under regulation:

$$\frac{\partial \pi_A}{\partial T} = [2 - (1 - \beta)^2 - S - T] - [T - \frac{1}{2}c\beta] = 0.$$

Solving jointly with S^* from the CP's problem yields $T^* = S^* = \frac{1}{48}(32 + 8c - 3c^2)$ and $\beta^* = 1 - c/4$.

Interpretation: Under regulation, both access and content prices T and S are lower than in the unregulated equilibrium for a given $c > 0$, and β is reduced from 1 to $1 - c/4$, which is halfway between the non-cooperative and the fully cooperative levels. Hence traffic is moderated, and consumers face lower total prices.

From these results, we can see that the level of content quality and the traffic induced by it are lower in the regulated case. Additionally, prices also decrease; for any $c > 0$, both T^* and S^* are lower in the regulated case than in the unregulated case. However, knowing that $\beta \geq 0$, we see that for any $c > 4$, $\beta = 0$. For this reason, we will only discuss the cases where $0 \leq c \leq 4$.

The main purpose of this regulation was not to increase consumer surplus or total welfare, but rather to share the costs of content quality and the associated traffic in a fair way. However, if this regulation negatively affects welfare indicators, it might not be desirable to adopt.

Welfare Comparison: Denote unregulated consumer surplus and total surplus by CS^{UR}, TS^{UR} and regulated by CS^R, TS^R . After substituting the equilibrium values into the respective surplus functions and comparing, we derive:

$$CS^R > CS^{UR} \quad \text{if } c < \frac{1}{3}(32 - 8\sqrt{13}) \approx 1.05,$$

$$TS^R > TS^{UR} \quad \text{if } c < \frac{1}{15}(100 - 4\sqrt{145}) \approx 3.45.$$

Interpretation: When network cost c is below about 1.05, consumers strictly gain from regulation (lower prices and moderated traffic). If c is below 3.45, total welfare is higher under regulation. Above these thresholds, the regulated reduction in β is too large relative to cost savings, harming either consumer surplus or total surplus.

7 Extension to n ISPs

Although our baseline framework assumes monopolies in both the access and content markets, the externality we analyze stems not from market power itself but from ISPs' failure to internalize the benefit they provide to content providers. Nonetheless, it is instructive to explore how introducing competition on one side might affect our conclusions. Accordingly, in this section we relax the monopoly assumption for ISPs: we allow n symmetric providers to compete *à la* Cournot by choosing the number of subscribers they serve, which naturally captures capacity decisions in a real-world broadband market. At the same time, we continue to model the content market as monopolistic, reflecting the differentiated products and significant market power of leading platforms. Below, I derive the equilibrium load factor β under various coalition structures and compute the corresponding Shapley values in this competitive setting, thereby extending our cost-sharing rule to a more realistic multi-ISP environment.

In this extension, I introduce competition on the access side while retaining a single, monopolistic content provider. This reflects the reality that ISPs typically offer a standardized connectivity service and compete fiercely for exclusive subscribers – once a household commits to one provider, it rarely splits its demand across multiple networks. Modeling ISP behavior as an n -firm Cournot game – where each firm chooses the number of consumers it serves – captures both capacity investment and market rivalry in a natural way. Moreover, the Cournot framework enjoys the convenient property that, when $n = 1$, it collapses to our original monopoly case, ensuring analytical consistency with the baseline model.

In contrast, content providers are typically highly differentiated—ranging from social media platforms and streaming services to OTT communication tools—and often wield greater market power than ISPs. Consumers view these offerings as complements to

their broadband connection rather than substitutes, and, as demonstrated in our baseline model, even a monopolistic CP optimally sets $\beta = 1$. This result would not change under content-side competition, so for analytical clarity we continue to model the content market as a single, monopolistic provider. All other assumptions about consumer heterogeneity, utility, and cost structure remain identical to those in the baseline framework.

Let us now turn to the access market, in which n symmetric ISPs compete *à la* Cournot by choosing their subscriber quantities q_i . Each ISP's profit reflects aggregate demand, the content price, and the traffic-related cost they face. Specifically, for ISP i we have:

$$\pi_i^A = q_i \cdot \left[2 - (1 - \beta)^2 - S - \sum_{j=1}^n q_j - c\beta \right].$$

Because our central focus is on how different coalitions internalize the traffic externality – i.e. how they affect the equilibrium load factor β – we will not delve into the full Cournot equilibrium for q_i , S , and T . Instead, we concentrate solely on deriving each coalition's optimal β .

7.1 Dynamics of coalitions

Because our assumptions about the CP's behavior remain unchanged – and under non-cooperative play the CP unilaterally chooses β – the competitive market equilibrium again yields $\beta = 1$ when all players optimize independently.

Conversely, the grand coalition comprising all n ISPs, the CP, and consumers attains the same social-optimum load factor as in the monopoly case, $\beta^* = 1 - \frac{c}{2}$, since it maximizes total surplus by fully internalizing the externality. More generally, any coalition that includes the CP and all n ISPs—regardless of whether consumers join—enjoys this same outcome.

As in the monopolistic framework, adding consumers to a coalition without the CP leaves β unchanged at 1: consumer participation does not mitigate the externality. Therefore, only those coalitions that include both at least one ISP and the CP can reduce β below its unregulated level. Hence, our subsequent analysis focuses on these ISP–CP coalitions.

Coalition of CP and k out of n ISPs: Suppose the CP forms a coalition with k of the n ISPs (with $1 \leq k \leq n$). Denote the total demand served by these ISPs as Q , with each participating ISP serving $q_i = Q/n$. The joint profit of this partial coalition is

$$\begin{aligned}\pi_{A_{1 \rightarrow k}}^C &= Q \cdot S + \frac{kQ}{n} \cdot T - \frac{kQ}{n} \cdot c\beta = \\ &= Q \cdot \left[2 - (1 - \beta)^2 - Q - \frac{n - k}{n} \cdot T - \frac{k}{n} \cdot c\beta \right]\end{aligned}$$

Derivation of β_k^ :* Taking $\partial/\partial\beta = 0$:

$$-2Q(1 - \beta) - Q \cdot \frac{k}{n} c = 0 \implies 2(1 - \beta) = \frac{k}{n} c \implies \beta_k = 1 - \frac{k}{2n} c.$$

Hence, as more ISPs join the coalition (i.e. k increases), the coalition internalizes a larger fraction of the traffic externality, reducing β . When $k = n$, we get $\beta_n = 1 - \frac{n}{2n} c = 1 - \frac{c}{2}$, matching the grand-coalition optimum.

Marginal Contributions: The marginal reduction in β from adding ISP A_k to a coalition of size $k - 1$ is

$$\beta_{\{A_1, \dots, A_k\}} - \beta_{\{A_1, \dots, A_{k-1}\}} = \left(1 - \frac{k}{2n} c\right) - \left(1 - \frac{k-1}{2n} c\right) = -\frac{c}{2n}.$$

Similarly, when the CP joins a coalition of k ISPs (which by itself has $\beta = 1$), the reduction in β is

$$\beta_{\{A_1, \dots, A_k\}} - \beta_{\{A_1, \dots, A_k, C\}} = 1 - \left(1 - \frac{k}{2n} c\right) = \frac{k}{2n} c.$$

Consumers never affect β , so their marginal contribution is zero.

7.2 Shapley values (competitive case)

Having identified each player's marginal contribution under every coalition, we now compute the Shapley values by averaging these contributions across all possible partition orders of the grand coalition. With $n + 2$ players (the CP, the consumers, and n ISPs), there are $(n + 2)!$ distinct orderings in which players might join or exit.

To organize the calculation, we partition these orderings into two classes determined by whether the CP or the consumers leave the coalition first. Within each class, suppose that k ISPs depart one by one before the first non-ISP player, then l additional ISPs exit before the second non-ISP player, and finally the remaining $n - k - l$ ISPs leave last. Here

k ranges from 0 to n , and for each k , l ranges from 0 to $n - k$. Table 3 enumerates these two groups of orderings and records each player's contribution in every scenario.

						Contributions of players			
Order of exiting (Partition order)						$A_{1 \rightarrow k}$	$A_{k+1 \rightarrow k+l}$	C	B
$\underbrace{A_1 \dots A_k}_{k \text{ times}}$	C	$\underbrace{A_{k+1} \dots A_{k+l}}_{l \text{ times}}$	B	$\underbrace{A_{k+l+1} \dots A_n}_{n-k-l \text{ times}}$		$\frac{c}{2n}$	0	$(n-k) \cdot \frac{c}{2n}$	0
$\underbrace{A_1 \dots A_k}_{k \text{ times}}$	B	$\underbrace{A_{k+1} \dots A_{k+l}}_{l \text{ times}}$	C	$\underbrace{A_{k+l+1} \dots A_n}_{n-k-l \text{ times}}$		$\frac{c}{2n}$	$\frac{c}{2n}$	$(n-k-l) \cdot \frac{c}{2n}$	0

Table 3: Players' calculated contribution to coalition in different scenarios - Competition

Explanation for Table 3:

- When the CP enters a coalition of k ISPs, it reduces β by $\frac{k}{2n}c$.
- When an ISP enters a coalition with j existing ISPs (but no CP), adding that ISP reduces β by $\frac{c}{2n}$.
- When an ISP enters after the CP has already joined j ISPs, the marginal reduction is still $\frac{c}{2n}$.
- Consumers never change β , so their contribution is always 0.

To derive the Shapley values, we compute each player's average marginal contribution across all $(n+2)!$ orderings. Since consumers never affect the load factor, their contribution is identically zero:

$$|\varphi_B| = 0.$$

The Shapley value for each ISP A_i (all symmetric, so they share the same value) is:

$$|\varphi_{A_i}| = \frac{1}{(n+2)!} \sum_{\text{all orders}} (\text{marginal contribution of } A_i) = \frac{\frac{n!}{n} \cdot \left\{ \sum_{k=0}^n \sum_{l=0}^{n-i} \left[(2k+l) \cdot \frac{c}{2n} \right] \right\}}{(n+2)!} = \frac{\frac{n!}{n} \cdot \frac{c \cdot (n+1) \cdot (n+2)}{4}}{(n+2)!} = \frac{c}{4n}.$$

Derivation Sketch: Summing over all orders, each ISP's marginal contribution $\frac{c}{2n}$ appears in exactly $\frac{(n+1)!}{2}$ orders out of $(n+2)!$, yielding $\frac{(n+1)!}{2} \cdot \frac{c}{2n} / (n+2)! = \frac{c}{4n}$.

Going on to the CP, the Shapley value for the CP is:

$$|\varphi_C| = \frac{1}{(n+2)!} \sum_{\text{all orders}} (\text{marginal contribution of } C) =$$

$$\frac{n! \cdot \left\{ \sum_{k=0}^n \sum_{l=0}^{n-i} \left[(n-2k-l) \cdot \frac{c}{2n} \right] \right\}}{(n+2)!} = \frac{n! \cdot \frac{c \cdot (n+1) \cdot (n+2)}{4}}{(n+2)!} = \frac{c}{4}$$

Derivation Sketch: In each ordering, CP's marginal reduction in β when entering a coalition of k ISPs is $\frac{k}{2n}c$. Summing k over all possible positions of CP in the ordering and normalizing yields $\frac{c}{4}$.

In summary, the Shapley values calculated for each player in the competitive case are:

$$|\varphi_{A_i}| = \frac{c}{4n}, \quad |\varphi_B| = 0, \quad |\varphi_C| = \frac{c}{4}.$$

By construction, the sum of all Shapley values equals the total reduction in the load factor—that is,

$$\sum_{i=1}^n \varphi_{A_i} + \varphi_B + \varphi_C = n \cdot \frac{c}{4n} + 0 + \frac{c}{4} = \frac{c}{2},$$

matching the gap between the unregulated equilibrium ($\beta^M = 1$) and the social optimum ($\beta_{ABC} = 1 - \frac{c}{2}$).

Crucially, this calculation shows that the content provider and the ISP side of the market each account for exactly half of the externality. Consequently, under a fair-share rule, CPs and ISPs should each shoulder half of the cost. When there are more symmetric ISPs, their collective share is divided equally among them.

8 Discussion and Conclusions

In this paper, we employed a cooperative game-theoretic approach to address the normative question: if content providers must contribute a “fair share” of broadband network costs, how should that share be allocated among ISPs, CPs, and consumers? By modeling three coalition scenarios—CP-ISP-consumer (grand coalition), CP-ISP, CP-consumer, and ISP-consumer—we computed equilibrium traffic levels (quality β) under each. We then used the Shapley value to attribute the total cost reduction (difference between unregulated $\beta^M = 1$ and social-optimum $\beta_{ABC} = 1 - \frac{c}{2}$) to each player. Our main finding is that both ISPs and CPs should each carry half of the traffic-related costs, while consumers

bear none. Extending to n competing ISPs, this half-share on the ISP side is split equally across them.

8.1 Synthesis of Key Findings

Non-Cooperative Inefficiency: In the absence of cost sharing, the equilibrium involves $\beta = 1$ as the CP maximizes profit by choosing highest quality, ignoring the external cost. This leads to excessive traffic, underinvestment incentives, and higher total prices ($S + T$) than socially optimal. Consumers pay for this inefficiency through inflated prices and congested networks.

Cooperative Benchmark via Shapley Value: By fully internalizing the traffic externality, the grand coalition reduces β to $1 - \frac{c}{2}$. The resulting total price of access plus content $S + T = c(1 - \frac{c}{2})$ is lower than the unregulated $S + T = \frac{2 + 2c}{3} + \frac{2 - c}{3} = \frac{4 + c}{3}$. The Shapley value shares the traffic-related cost reduction $\frac{c}{2}$ equally between the ISP and CP, assigning zero to consumers. This allocation is the unique one satisfying efficiency, symmetry, dummy-player, and additivity axioms, giving a transparent and principled “fair-share” rule. The sharing rule is robust to a competitive specification of the model, where ISPs compete Cournot-style.

Regulated Implementation: If regulators impose a policy requiring the CP to pay half the traffic cost per user per unit quality, while ISPs absorb the other half, the equilibrium shifts to $\beta = 1 - \frac{c}{4}$. Consequently, total prices S and T both fall relative to unregulated levels for moderate c . Consumers pay lower combined prices and traffic is moderated. For a wide range of parameter values, a Shapley-value-consistent cost sharing yields efficiency gains.

8.2 Policy Implications

Our results yield several actionable insights for policymakers:

1. **Principled Cost Allocation:** If regulators decide to require CP contributions to network costs, they should use a rule akin to the Shapley allocation rather than ad hoc criteria. Specifically, CPs and ISPs each shoulder 50% of traffic-related costs; the ISP half is split equally among all competing ISPs in proportion to traffic volume or

subscriber shares. This ensures fairness and avoids distortions from pure bargaining power.

2. **Targeted Application for Large CPs:** Because small CPs (with low traffic volumes) might face disproportionate burdens under a uniform cost share, policymakers could set a traffic threshold (e.g., a monthly GB volume) above which the Shapley rule applies. This aligns with BEREC’s recommendation to limit levies to “very large traffic generators.”
3. **Avoid Consumer Burden:** Our cooperative analysis shows consumers have zero Shapley value—they do not cause the externality in equilibrium. Thus, regulators should not tax end-users directly for network costs, as that would violate fairness axioms and likely reduce consumer welfare.
4. **Regulatory Coordination:** To prevent piecemeal bilateral agreements—or “pay-for-preferred-peering” deals that discriminate against non-paying CPs—regulators could adopt a uniform, industry-wide levy based on Shapley principles. This fosters a level playing field and minimizes legal disputes (as seen in the South Korean case).

8.3 Limitations and Future Research

Although our cooperative Shapley analysis offers a clear normative benchmark, several limitations warrant further investigation:

- **Simplified Demand and Utility:** We assumed uniform consumer valuations $v_i \sim U(0, 1)$ and a single quadratic quality term $(1 - \beta)^2$. Real-world demand may exhibit more complex preferences (e.g., multi-dimensional content genres, nonlinear platform differentiation). Extending to richer preference structures may alter equilibrium β values and hence Shapley-derived shares.
- **Multiple Content Providers:** We assumed a single monopolistic CP. In practice, there are numerous CPs with heterogeneous monetization rates, content portfolios, and willingness to pay. A multi-CP cooperative framework would require computing Shapley values across a larger player set, and smaller CPs might receive negligible Shapley shares, raising equity concerns.

- **Dynamic Investment and Technological Change:** Our static framework abstracts from dynamic aspects such as investment in compression technologies by CPs or new network architectures (e.g., edge computing). Such dynamic complementarities or strategic investments could shift the “value” of future coalitions, suggesting a dynamic cooperative game or stochastic Shapley allocation.
- **Empirical Calibration and Implementation:** Applying the Shapley rule in real markets requires estimating c (marginal cost per user per unit quality) and attributing traffic shares precisely. Empirical studies are needed to calibrate these parameters, measure traffic-cost relationships, and test whether predicted welfare gains match observed outcomes in pilot programs.

Addressing these limitations could provide a more nuanced view of fair share policies, especially in heterogenous markets with multiple platforms and evolving technologies.

8.4 Concluding Remarks

In summary, this paper demonstrates that the Shapley value offers a transparent, axiomatic foundation for “fair cost sharing” in broadband networks. By identifying that ISPs and CPs each incur half of the traffic-related externality, the Shapley rule informs both private bargaining and regulation—ensuring that cost allocations reflect marginal contributions to network usage. Although consumers ultimately pay access fees, they do not directly drive the incremental network costs attributable to content quality and are therefore assigned zero Shapley share.

Our comparative static and competitive-ISP extensions show that a regulatory mandate requiring CPs to cover half of the marginal traffic cost can, under plausible parameter values, improve consumer surplus and total welfare. However, the analysis also highlights critical thresholds: if network cost c is too high, such a mandate could reduce welfare by over-reducing content quality. As a result, any policy implementation should be accompanied by cost transparency, threshold rules for CP eligibility, and mechanisms that link cost-sharing revenues to network expansion and quality improvements.

Ultimately, “fairness” in cost sharing has both positive (efficiency) and normative (equity) dimensions. While this paper emphasizes the positive, game-theoretic foundation via Shapley axioms, normative judgments about consumer versus CP burdens remain

important. We believe the Shapley value clarifies one dimension of fairness—marginal contribution—but leave room for policymakers to weigh distributional goals, innovation incentives, and dynamic investment needs.

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