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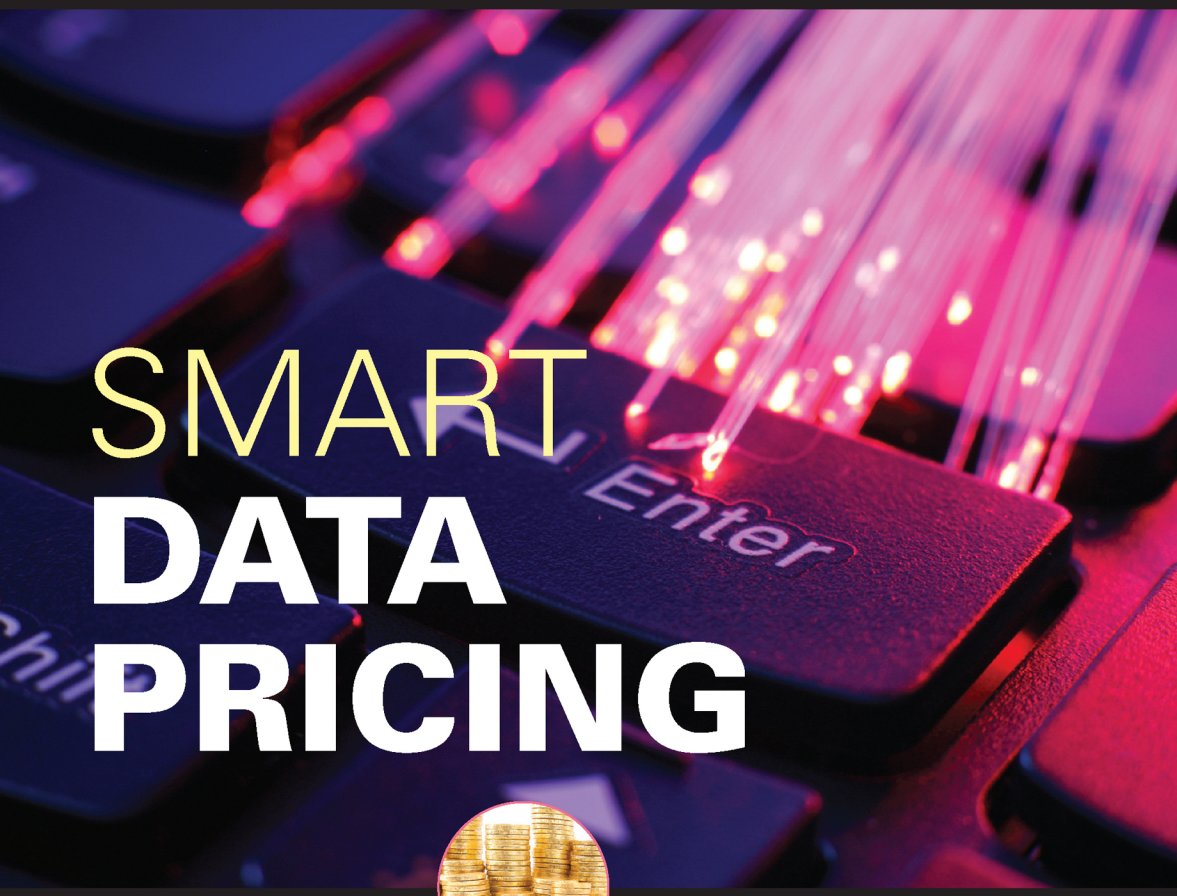

SMART DATA PRICING

Editors

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WILEY

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FOREWORD

Smart phones, tablets, and other video and music streaming devices fuel an exploding demand for network, cloud, and content services. Providers find it difficult to increase revenue to match the investments required to address this demand. The wireless networks are getting stressed and the quality of service suffers. The experience of other industries suggests that smarter pricing mechanisms might improve the matching of resources and users and the revenue of providers, thereby increasing user welfare both in the short term and long term. Researchers are exploring this possibility and a number of recent workshops on this topic attest to the perceived urgency of developing effective approaches.

This collection of papers presents the analysis of the pricing of network services and content conducted by leading researchers from industry and academia. The topics include the following: the tension between the users' preference for simple tariffs and potential benefits of more complex schemes; the users' sensitivity to quality of service and their willingness to shift demand; economic incentives for efficient caching and infrastructure improvements; and pricing schemes for content and for cloud resources.

Researchers will welcome this timely and broad coverage of Smart Data Pricing (SDP).

Jean Walrand
University of California, Berkeley, CA

PREFACE

As the demand for data in both wired and wireless broadband networks continues to grow every year, Internet Service Providers (ISPs) are increasingly turning to pricing both as a congestion management tool and as a revenue generation model. This evolution in the pricing regime is evidenced by the elimination of flat-rate plans in favor of $10/GB or higher usage based overage fees in the United States and various other countries in Asia and Europe. This rapid transition from unlimited data plans to a reign of penalty-based mechanisms, including throttling, capping, and usage-based fees, all within a span of just 4 years as witnessed in the United States is shown in Figure 1. Consequently, Smart Data Pricing (SDP) will play a major role in the future of mobile, broadband, and content. SDP refers to a departure from the traditional flat-rate or byte-counting models to considering pricing as a network management solution. Thus, SDP will impact not only end users and network operators, but will also engage content providers, policy makers, mobile advertisers, vendors, and device suppliers. SDP incorporates the following principles:

1. ***Pricing for end-user Quality of Experience (QoE) and not just linear byte-counting***: Simple policies like usage-based pricing (byte-counting) (i) force users to pay the same amount per unit of bandwidth consumed irrespective of the congestion levels on the network, and (ii) fail to account for the fact that different applications have different bandwidth requirements to attain a certain QoE for the user. SDP should try to match the price for delivering application-specific desired QoE requirements of the user to the ISP's congestion cost at the time of delivery.
2. ***Application layer control to impact physical layer resource management***: Today's smart devices, with their easy-to-use graphical user interfaces, can potentially enable consumer-specified choice for access quality. Whether done manually or in an automated mode, users' specifications of their willingness to pay for their desired QoE of different applications can be taken in as inputs at the APP layer and used to control PHY layer resource allocation and media selection (e.g., WiFi offloading versus 3G). But enabling this interaction requires consumer trials to understand how to design incentives and create interfaces that can be effective in modifying end-user behavior.

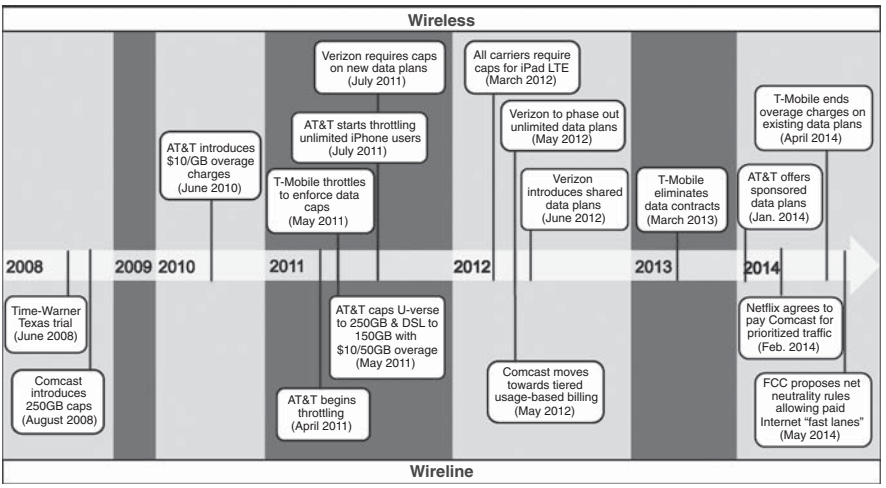

Figure 1 Timeline of the evolution in pricing plans in the United States.

3. ***Incorporating edge devices as a part of the network management system***: Instead of only managing traffic in the network core, SDP explores ways to make edge devices (e.g., smart mobile devices and customer-premise equipments like gateways) a part of the network resource allocation and management system. For example, instead of throttling traffic in the network core using the policy charging and rules function (PCRF), the edge devices (e.g., home gateways) themselves can locally regulate demand based on a user's budget, QoE requirements, and network load or available prices. Such measures to push control from the network core out to end users, while preserving the end-to-end principles of the Internet, have been gaining attention among networking research groups (for example, the M3I[1] collaboration in Europe).

SDP can refer to (a) time/location/app/congestion dependent dynamic pricing, (b) usage-based pricing with throttling/booster, (c) WiFi offloading/proactive caching, (d) two-sided pricing/reverse billing/sponsored content, (e) quota-aware content distribution, (f) shared data pricing, and any combination or extension of the above. For instance, two-sided pricing can include QoE enhancements, or it may simply refer to content providers partially subsidizing data. SDP can benefit end users, network operators, and content providers by improving users' Quality of Experience; lowering ISP congestion and CapEx/OpEx, thus increasing their revenue/profit margin and decreasing churn, and encouraging more consumption and ad revenue for content/app providers. But to realize these benefits, SDP requires pricing models that capture the interplay between technical and economic factors, as well as interfaces between network providers and content & application providers; effective user interface designs;

[1] http://www.m3i.org/

field trials; and a combination of smart ideas, systematic execution, and informed policy.

This volume of collected essays on SDP has immensely benefitted from the annual SDP Forum, which organizes workshops to bring together industry experts, academics, and regulators for in-depth discussions on the topic. SDP 2012 was held in Princeton, New Jersey, and the SDP 2013 and 2014 Workshops were was held in conjunction with IEEE INFOCOM in Turin, Italy and Toronto, Canada. The workshops have been attended by professionals from AT&T, Verizon, Comcast, NECA, Alcatel-Lucent, Cisco Systems, Qualcomm, Microsoft, ACS, and many other leading networking companies. It therefore comes with little surprise that several of the chapters in this volume have been contributed by industry researchers and showcase some cutting-edge research in this area.

The first three chapters of this book discuss SDP's feasibility in the current Internet ecosystem. The first chapter looks back on previous efforts to promote SDP and asks whether the current market climate will be more receptive. The next chapter approaches SDP's feasibility from a customer perspective, using empirical data to examine their price sensitivity. Finally, the third chapter incorporates regulatory concerns by examining network neutrality in the context of content caching.

The next three chapters address SDP's technical feasibility. The first chapter in this section develops a pricing model that accounts for the flexibility and predictability of customer demand. The second chapter focuses on wireless networks, showing how pricing can be used to make wireless resource allocation more efficient. The last chapter focuses on SDP's interface between ISPs and users, examining how the ISP can communicate prices to users through interfaces on their devices.

The next three chapters of the book shift to variants on usage-based pricing, a particular form of SDP. The first chapter examines whether usage-based pricing can in fact help ISPs by quantifying the distribution of infrastructure costs among ISP customers. The next two chapters then turn to differentiated pricing: the first of these develops a model for differentiated usage-based pricing, while the second examines the benefits of non-differentiated and differentiated pricing for ISPs and end users.

Another form of SDP, content-based pricing, is discussed in the next four chapters. The first chapter discusses a variant of usage-based or capped pricing, in which content providers subsidize the delivery of their content to end users, sponsoring users' Internet access. The second chapter shifts the focus to content delivery networks and the impact of competition on their pricing and investment, while the third chapter discusses the economics of a hybrid model in which content delivery can be offloaded to a secondary P2P network during congested times. The last chapter considers the economics of content providers, focusing on how the owners of user-generated content platforms, e.g., social networking websites, can best monetize this content.

The next four chapters discuss technical aspects of realizing economically efficient models of content delivery. The first chapter investigates the idea of opportunistic content transfer, offloading traffic to times of lower congestion with a monetary discount given during times of lower congestion. The next chapter considers a similar idea, in which sessions like content transfers can be spread over time, but with prices determined by the deadline of each session's completion. The third chapter focuses

on video content, and shifts the focus away from ISPs to consider how a user might distribute a budget for consuming videos over time. Finally, the last chapter considers multicast technology and how it can alleviate network congestion.

The last two chapters of the book consider pricing in the cloud. The first chapter investigates and compares three different schemes for pricing data center resources, namely real-time instance pricing, deadline-based service level agreements, and time-dependent pricing. The last chapter proposes using combinatorial auctions to price and allocate resources in a data center while taking into account its electricity constraints.

The diversity of topics explored in these book chapters reflects SDP's broad potential impact. Indeed, SDP brings together ideas from such diverse fields as network engineering, economics, human-computer interaction, data science, and technology policy to answer fundamental questions about broadband pricing. Yet there remain significant emerging themes which this book does not cover. For instance, little rigorous analysis has been done on shared data plans, which have recently become mainstream in the U.S. Perhaps more significantly, "network neutrality" is emerging as a fundamental issue, with new regulations from the FCC and Netflix's agreement with Comcast to pay for a separate "fast lane" for its streaming traffic. And as more and more devices become connected to the Internet, pricing for the Internet of Things is becoming an important question. The emergence of these and other topics will ensure that SDP remains an exciting and relevant research topic in the years to come.

Soumya Sen, Carlee Joe-Wong, Sangtae Ha, and Mung Chiang

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PART I
Smart Data Pricing in Today's Ecosystem

1 Will Smart Pricing Finally Take Off?

ANDREW ODLYZKO

1.1 INTRODUCTION

Will smart pricing dominate telecommunications? We certainly do see growth in sophisticated pricing in many areas of the economy. Congestion charges for cars entering central business districts and "smart" electric meter deployments are spreading. Airlines are even beginning to auction seat upgrades [1]. And there is no shortage of desire for smart pricing in telecommunications. For a survey of recent developments, see Reference 2. Many new technological developments, such as software-defined networking (SDN), are touted as facilitating differentiated services and differentiated pricing. The overwhelming consensus of the industry, as well as of the research community, and of regulators, is that flat rates are irrational. Thus, for example, in 2011, Jon Leibowitz, the then-Chairman of the US Federal Trade Commission could not "quite understand why something like metering hasn't taken off yet." (See Reference 3 for references to this and similar recent quotes, as well as for a summary of the arguments in favor of flat rates.)

Yet there are reasons for caution in the rush to smart pricing. After all, the modern consensus about its desirability is not new. It goes back centuries, to the days of snail mail. Furthermore, industry has often either stumbled onto flat or almost flat rates, or been forced into them, all against its will, and ended up benefiting. Thus, for example, US wireless service providers have been boasting of the low per-minute voice call revenues that reign in United States, much lower than in most of the world. What they universally neglect to mention is that these low prices are the result of the success of the block-pricing plan introduced by AT&T Wireless in 1998, which also eliminated roaming and long-distance charges. This plan, the result not of a careful study of historical precedents or the economics of communications but rather the fruit of a desperate carrier looking for a way to gain customers, was widely derided but proved unexpectedly popular. It forced the rest of the industry to follow suit with

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similar plans and led to large increases in voice usage (see, e.g., the chart in Reference 4). The end result is that the United States has the world's highest per-subscriber voice usage, yielding those low average per-minute prices that the industry boasts of. Probably not coincidentally, US wireless service providers are among the world's most profitable. This story, and others similar to it, should make one cautious about rushing to follow the industry consensus. This is true even when such a consensus is fortified by scholarly studies, because those tend to be even more biased toward fine-grained pricing. The telecom industry and telecom researchers have historically been notorious for not understanding what is in the industry's own interests.

The traditional preoccupation with smart pricing is likely to be reinforced by the economics of telecom. Contrary to common opinion, it is not all that capital intensive. As is demonstrated in Section 1.8, telecom is simply not in the same category as such large and important industries as electricity or roads when it comes to the ratio of capital investment to revenues. Telecom is primarily about service, customer inertia, and territorial strategic plays (where the territories may be physical or virtual).

Although the telecom industry is not very capital intensive, communications is extremely valuable and any society is willing to pay astonishing amounts for it. As an example, by some measures, the United States spends almost 50% more on telecom services than it does for electricity. (See Section 1.5 for more data and references.) Furthermore, in spite of all the complaints from the industry about its supposedly impoverished state, there appears to be very large profits in many parts of it. As this passage is being written in the summer of 2013, Verizon is in the process of buying out Vodafone's 45% stake in the Verizon Wireless unit for $130 billion. This means that the whole of Verizon Wireless is being valued at almost $300 billion. As will be shown in Section 1.9, that is about four times the cost of replacing all the tangible assets of that enterprise. It is also almost enough to replace the entire US telecom infrastructure, both wireless and wired, with the latter redone in fiber. This is anomalous by traditional standards, but then, as will be discussed in Section 1.9, the entire economy is behaving anomalously, with very high corporate profits, low interest rates, and low capital investment. Whether this is a temporary aberration, or whether we are in a new economic era, remains to be seen. However, telecom is very much in the mainstream of this historically unusual behavior, and so many traditional yardsticks of financial performance may not apply.

While the telecom industry has often been blind to profitable opportunities, it has always been aware that high profits are possible. However, it has usually faced difficulties in using their favorite methods for profit extraction because of various combinations of legal and regulatory constraints and the peculiar nature of demand for communication services. Table 1.1 shows an approximation of current prices paid by users for varying amounts of data from various services.

This table demonstrates the main problem faced by telecom. The most valuable information can often be conveyed in just a few bits. Thus, for example, in the early days of postal services, when receivers paid on delivery, information would often be transmitted in the form of small modifications in the address. The addressee would then scan the envelope, figure out what the message was, and refuse to accept (and pay for) the letter.

TABLE 1.1 Price per Megabyte

SMS	$1000.00
Cellular voice	1.00
Wireline voice	0.10
Residential Internet	0.01
Backbone Internet	0.0001

Practices from two centuries ago may seem irrelevant, but in fact they are very instructive, as the basic economic issues have always been the same, even as technology has changed drastically, cf. [5]. Thus, for example, today, we have the telecom industry investing heavily in deep packet inspection. In the past, post offices had employees hold letters up against burning candles to make sure that there were no enclosures that were subject to extra fees. The basic incentive is to extract as much value as possible, and that usually requires fine-grained pricing to achieve successful price discrimination. But usually, in communication as well as in transportation, limits are placed on what service providers are allowed to do. The net neutrality debate is just another instance of the ancient conflict between economic efficiency and fairness in markets [6]. Giving unfettered control of any critical service to any provider, or an oligopoly of providers, either *de jure* or *de facto* (by allowing natural monopoly mechanisms to operate), is equivalent to abolishing property rights with the usual negative impacts on innovation and efficiency. Hence, we have almost always had constraints, such as those of common carriage. The real question is about the appropriate level of constraints.

Public talk of capacity limits is often just a public relations measure, designed to overcome opposition to service provider strategies. Thus, for example, in early 2013, Michael Powell, the President of the US cable industry association [and former Chairman of the Federal Communications Commission (FCC)] admitted, contradicting many earlier declarations by a variety of executives and experts, that "cable's interest in usage-based pricing was not principally about network congestion, but instead about pricing fairness" [7]. Whenever business leaders talk of "fairness," it is generally safe to assume that they are really after extracting more revenues through differential pricing. This is neither a novel nor is it nefarious. In fact, differential pricing was and is at the core of regulatory economics, as it can be used to promote social welfare, and has been frequently mandated by governments. However, historically, the degree of price discrimination that was allowed varied depending on economics, with more discrimination being allowed when the costs of providing those services have been large [8]. The question for the near future is whether modern telecom should be allowed more power to discriminate. Further, even if it is given that power, one should consider whether it would be wise to use it. The right answer depends on the balance between growth in demand and improvements in technology.

The main problem, past, present, and future, that is faced by telecom is that the most valuable information usually requires just a few bits to convey. The second main problem is that because of technological progress, transmission capacity is growing. Thus the industry is faced with the challenge of persuading users to pay for big pipes

when the additional value that enlarging those pipes provides is not all that high. (There are arguments that the value of transmission capacity, as well as that of computing power and storage, should be measured on a logarithmic scale, so that going from what is now a slow 1 Mbps link to a 1 Gbps one corresponds only to an increase in value from 6 to 9, cf. [9].) At the moment, that additional capacity is consumed largely by video. But the value is still dominated by the low bandwidth voice and texting.

The general conclusion of this work, based on the study of trends in demand and supply, is that in wireline communication, the critical issue faced by the telecom industry is not handling overpowering exafloods of traffic, as has often been claimed, cf. [10–12], but stimulating demand to fill the growing capacity of transmission systems [13]. The most effective way to do that is to offer flat rates and open access to encourage innovation. To the extent that any market segmentation is needed, it is best handled by offering flat rate services with different peak speeds. Pricing by volume of traffic (whether using caps or other schemes) may be attractive at the moment to service providers preoccupied with trying to protect their traditional subscription video service revenues. However, it is an ineffective instrument that does not address any of the issues well and, in the long run, is likely to damage not only the economy as a whole but also the profits of service providers. Any truly "smart pricing" measures, such as congestion charges, are likely to be detrimental to the industry.

These general conclusions for wired communications apply directly mainly to the richer and more industrialized countries. Even in those, there is likely to be exceptional situations where the cost structure forces some "smart pricing" approaches. For poor countries, the best choices along the frontier of feasible technological and business models is likely to lean further toward "smart pricing." This would be consistent with the general observation, cf. [5], that at the consumer level, sophisticated pricing is most appropriate for large and relatively infrequent transactions, and simple pricing for small and frequent ones. This is also what we observe in the market today, with the greatest proliferation of "smart pricing" in less-developed countries, where the relative burden of telecommunications charges is higher.

In wireless communication, the optimal choice even in rich countries appears to be different than that for wireline, because of a different balance between feasible supply and potential demand. There have been widespread projections that wireless data traffic would continue to double each year, as it had done for several years. Those are now being disproved, as growth rates are declining (see Section 1.13). Still, those rates are high, and there is far more traffic that are likely to use the radio path if that were feasible, as wireless data traffic is under 5% of wireline. Coupled with the low value of most of this data, and the resulting low likelihood of service providers being able to extract large new revenues, it appears probable that the incentives for the industry will be to constrain usage and to implement differentiated quality of service to protect the most valuable low bandwidth applications. So somewhat finer-grained pricing is likely to prevail in this domain than in wireline. Still, the need to limit what Nick Szabo [14] has aptly called the *mental transaction costs* involved in fine-grained pricing, and related concerns, is likely to restrict the complexity of schemes that succeed. The sophisticated pricing plans so beloved of researchers are likely to be confined to

areas such as business-to-business dealings and may be of limited applicability even there.

However, the strong prejudice in favor of "smart pricing" among both industry leaders and academic researchers guarantees that many schemes will be developed, and quite a few will be deployed. Chances are that, as was true of many sophisticated prioritization schemes developed for voice private branch exchanges (PBXs) or early data switches, they will not see much use. But for those cases where they might be used, it appears that most of current research, as well as academic instruction, is missing some important ingredients. As is discussed in Section 1.12, it will likely be important to explore the most effective ways to introduce noise and other impairments into communication systems to provide differential quality of service. (On the other hand, there will likely also be demand for methods to detect such actions.)

The next section reviews briefly some of the main fallacies that invigorate the push for "smart pricing." This is followed by a section on some missed opportunities in telecommunications, demonstrating how this industry tends to "stumble to success," pursuing mistaken goals, and prospering by accident. Section 1.4 has a very brief discussion of the reasons telecom has been so poor at innovating in services and is likely to remain poor in the future. Section 1.5 discusses this industry's place in the entire economy. Section 1.6 points out that high profits have not infrequently been obtained in this sector. Section 1.7 sketches the main changes that have taken place in the money flows in telecommunications in recent decades. Section 1.8 demonstrates that, contrary to general opinion, this industry is not all that capital intensive. Section 1.9 discusses some of the puzzles of the modern economy and the degree to which the telecom industry exhibits similar behavior. Section 1.12, cited earlier, discusses some missing ingredients in modern research and education, should "smart pricing" become widespread. Sections 1.10 and 1.11 take a historical look at some earlier work on telecom pricing and the degree to which it reflected the prejudices we observe today. Sections 1.13 and 1.14 then discuss the growth in the demand for data traffic and improvements in transmission technologies and what the contrasts are with those that for optimal pricing strategies. Finally, Section 1.15 provides the conclusions.

1.2 TELECOM MISTAKES

Many of the basic but general issues that have a bearing on the possible adoption of smart pricing have already been explored in the literature (see, e.g., [5, 15–17]) and so will be touched on very lightly here. However, they do need to be mentioned, because there are many misapprehensions about the nature of telecom and these issues often have an important bearing on the optimal choices of pricing policies. For example, we are constantly told that content is king. (Content is taken here to mean material prepared by professionals for wide distribution and not, as some use it, to denote anything in digital form.) But

Content is not king.