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Balancing information rents and service differentiation in utility regulation

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ABSTRACT

In the regulation of natural monopolies such as regional utilities, several goals must be balanced. In this paper, we focus on the trade-off between information rents and service differentiation. Consumers in different regions may prefer different service levels and service mixes. The services provided should therefore ideally be aligned with the preferences of regional consumers. The utilities, however, have superior information about the cost of different services. This allows them to extract information rents by claiming high costs for the provided services. A relative performance evaluation in the form of benchmarking is typically used to limit information rents, but benchmarking is less efficient when service profiles are heterogenous. Hence, there is a trade-off between minimizing information rents and maximizing the adjustment to consumer preferences via service differentiation. In this paper, we study this trade-off in a simple principal–agent model and discuss how it may limit the usefulness of recent regulatory frameworks based on dialog and negotiations with utilities about which services to provide.

1. Introduction

Large infrastructure industries such as the networks to distribute electricity, gas, and water, commonly referred to as distribution system operators (DSOs), are characterized by considerable fixed costs and relatively low marginal costs. They, therefore, constitute natural monopolies and are generally given licenses to operate as legal monopolies. Monopolies have limited incentives to reduce costs and will tend to under-produce and over-charge the services provided since they are not subject to the disciplining forces of the market. Most countries, therefore, empower regulators to act as a proxy purchaser of the services, imposing constraints on prices and the modalities of production. One of the instruments used in the regulation is benchmarking, i.e., the comparison of different utilities with the aim of determining reasonable costs for the services provided.

Modern economic theory views the regulatory problem as a game between a principal (the regulator) and a number of agents (the regulated firms). The regulation problem is basically one of controlling firms that have superior information about their technology and their cost reducing efforts as compared to the regulator. Using relative performance evaluation and benchmarking, the regulator can partially undermine the information asymmetry. The regulatory toolbox contains many alternative regulatory proposals based on more or less formalized relative performance evaluations, including cost-recovery regimes (cost of service, cost-plus, rate of return), fixed price (revenue) regimes (price-cap, revenue-cap, RPI-X), yardstick regimes, and franchise auction regimes (see also Agrell and Bogetoft (2018)).

In the case of DSO regulation, regulators have mainly focused on providing incentives to lower costs for given services. The trade-off between service levels and information rents has not been much of an issue because the demand for services has largely been considered inelastic and relatively stationary. The aim of the regulation has therefore been to lower the historical cost levels. The most commonly applied regulation is the RPI-X approach based on the simple idea of Littlechild (1983). The RPI-X formula implies that historical costs cannot increase more than the growth rate of a retail price index minus a target productivity growth, X, intended to capture the general productivity growth and possibly minus a specific requirement, X_i, intended to ensure that utility i gradually eliminates its historical inefficiency compared to best practices.

According to Joskow (2014), as incentive regulations have evolved, the focus has shifted from reducing operating costs to investment and various dimensions of service quality. Many countries have indeed introduced some quality incentives, typically by add-on models that, for example, penalize the DSOs for energy not delivered during blackouts. Likewise, many regulators have shifted the cost focus from pure operation costs, Opex, to total expenditures, Totex, which also includes the capital expenditures, Capex.

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Recently, the infrastructure sectors have also started to discuss the need for new services and the regulatory adjustment needed to support the introduction of such services. A main driver of this has been climate challenges and the need for a green transition. The green transition is, for example, expected to necessitate reinforcements of the electrical grid due to a growing number of electric vehicles and a more widespread use of decentralized power generation. Likewise, the climate challenges are raising the need for investment in water installations to accommodate increased rainfalls and pollution of wells. Such changes could challenge the RPI-X approach. When allowed revenues are largely based on historic costs rather than expected future costs, it may be hard to accommodate the necessary adjustments and changes in focus. To properly compensate firms for the costs associated with service adjustments, the regulator may have to rely more on the firms' private information about future costs. This entails a trade-off between the gains from making service adjustments and the costs of increased information rents caused by asymmetric information.

One way for regulation to become more forward-looking is to rely on yardstick regulation, where the allowed revenue is determined ex post based on actual costs of peer firms. Yardstick regulation is used in, for example, the Norwegian regulation of DSOs in the electricity sector.

Another approach is to introduce an ex ante dialog about the future services desired and the cost of providing them. Examples of this approach include the Office of Gas and Electricity Markets' (Ofgem's) RIIO framework to regulate British DSOs and the Water Industry Commission for Scotland's (WICS') regulation of Scottish Water. Both frameworks were designed with the aim of encouraging regulated firms to focus on delivering outputs that are valuable to consumers rather than solely focusing on economic efficiency.[2] Within each framework, the regulated firms are required to consult with their stakeholders and demonstrate how their business plans have been affected by stakeholders' views. The outputs pursued by each firm, therefore, depend on stakeholders' preferences in each of the geographic areas.

This paper focuses on the trade-off between service differentiation and information rents. That is, on ensuring that the right service mix is pursued compared to consumers' preferences while also minimizing information rent. More generally, as a contract design problem, it focuses on the trade-off between coordination of production and motivation of the agents, cf. e.g., Milgrom and Roberts (1992) and Bogetoft and Olesen (2004). We study a simplified example of the problem where consumers in one area prefer a combination of services that is different from the preferred combination of services of consumers in another area. The regulator would therefore, in a first-best world, like the two monopolies to produce different service combinations. In a second best world, however, this comes with a motivation cost since it complicates the comparison of the two firms in a relative performance evaluation and in turn leads to higher information rents.

Specifically, we consider a principal–agent model where the regulator, as the principal, negotiates with two utilities (the agents) on their production of two different services. Remuneration is based on ex post costs using yardstick competition and the aim of the regulator is to maximize the consumer's net-value, i.e., the consumers' benefits from the services provided minus the costs they have to pay. We show that in some cases, and despite different preferences, it is optimal to let the two utilities produce the same services since the information rents associated with a diversified service mix outweigh the added value to consumers of a service differentiation. More generally, the second best service mixes are biased toward each other compared to the first-best mixes.

The paper proceeds as follows. Section 2 reviews related literature and provides regulatory examples that serve as a background to the problem we study. Section 3 presents the model by introducing assumptions about costs and utility functions and by formulating the regulator's contract design problem. In Section 4.1, we consider the optimal production plans under perfect information and in Section 4.2, we consider the case of asymmetric information. In Section 5, we discuss how different problem features impact the information rents. Section 6 concludes.

2. Background and literature

Regulation of natural monopolies is an example of the principal–agent problem. Section 2.1 therefore reviews the agency literature to which our paper is most closely related. Section 2.2 draws on contract theory to describe the concept of coordination as a goal for contract design and Section 2.3 reviews some regulatory examples that serve as a background for the problem we study.

2.1. Agency theory

The problem of regulating a monopolist with private information has been studied in the framework of the principal–agent literature since the pioneering contributions by Loeb and Magat (1979), Baron and Myerson (1982). The application of principal–agent methodology to the contractual relationship between regulators and regulated firms has since been named 'the new economics of regulation' by Laffont (1994).

Principal–agent models are widespread in economics, cf. e.g., Sappington (1991), and is commonly covered in modern economic textbooks. There are also many excellent textbooks focusing specifically on principal–agent models, c.f. e.g., Laffont and Martimort (2001) and Macho-Stadler and Perez-Castrillo (2001). In the context of utility regulation, the regulator is responsible for ensuring that the services requested is obtained from the utilities at the lowest possible costs. To do so, the regulator (principal) acts like a pseudo buyer on behalf of the end-users. The regulator contracts with one or more utilities (agents). This is a classical principal agent relationship with one principal and one or more agents. As always, such relationships may be subject to both moral hazard and adverse selection problems. Moral hazard refers to the motivation problems arising when the agents take hidden actions or receive hidden information after contracting, while adverse selection refers to problems related to hidden information acquired before contracting. In moral hazard problems, the solution is typically to make the agents partly responsible for the outcome. This leads to sub-optimal risk sharing when the agents are risk averse. In adverse selection settings, the issues are typically related to the superior information the agents hold about their conditions, e.g., their cost functions. This enable low-cost agents to charge excessive cost by claiming to be high-cost types. To handle this, the principal can ration, i.e., avoid buying from high-cost agents. Also, the principal can introduce mechanism that allow the agents to credibly signal their cost type. Such signaling or revelation mechanisms are typically organized as menus of contracts that the agents can choose from.

In this paper, we also focus on a hidden information problem by assuming that the utilities have superior information about their cost structure before contracting. In addition, we generally exclude the possibility of rationing. That is, we assume that the regulator wants to avoid any utility go bankrupt. Since low-cost utilities can claim to be high-cost utilities, and since the latter are not allowed to go bankrupt, this further increases the excess costs that utilities can extract. The difference between the payments received be an agent and its actual costs is typically referred to as information rents.

A traditional way to limit information rents is to do relative performance evaluations or benchmarking. This works well when there is some correlation between the production economic conditions that the different utilities face. By observing the cost and services in other utilities, the regulator can limit the cost structure a given utility can credibly claim. Benchmarking based regulations of utilities are widespread,

[2] See for example Ofgem (2010) and Water Industry Commission for Scotland (2013).

in particular in Europe, cf. e.g., Agrell and Bogetoft (2017, 2018). In this paper, we will also use a benchmarking approach to limit what different utilities shall be paid. In fact, in the main part of the paper, we shall use a very simple type of yardstick competition to make our calculations easy to follow.

This paper is related to that of Antle and Bogetoft (2019), who show that an agent's superior information about the relative costs of different products or activities leads to inertia in the mix of products or activities pursued, i.e., a favoring of the status quo that is referred to as 'mix stickiness'. The more the principal varies the production plan, the larger the agent's ability to claim high motivation costs. Therefore, the principal may not want to adapt the production plan fully. In this way, the principal trades off coordination against the goal of reducing information rents. The model framework thus sheds light on the trade-off between coordination and motivation. Optimal coordination is not achieved because of motivational problems. Similarly to Antle and Bogetoft, we study a principal–agent model in which the agents produce two outputs. As an extension to the model considered by Antle and Bogetoft, we consider the problem in the context of utility regulation and in a setting where the principal does not have any historical information. Instead, the principal needs to regulate several agents while balancing the goal of coordination between the produced output mix and consumers' preferences against the goal of minimizing information rents.

2.2. Coordination as a goal in contract design

Coordination of production as a goal in contract design has been described by Bogetoft and Olesen (2004) as the objective of making sure that the right producers are producing the right quantity of the right products at the right time and place. In the context of utility regulation, coordination of production can be seen as the alignment of the combination of services desired by consumers and the combination of services produced by the regulated firms. In a first-best world with perfect information about the firms' production possibilities and consumers' preferences, the marginal rate of substitution in production must equal the marginal rate of substitution in preferences.

Coordination of production is also related to the concept of allocative efficiency. In the productivity analysis literature, allocative efficiency requires that the firm is able to select the correct mix of services such that an optimal balance between the benefit and cost sides is achieved.[3] If allocative efficiency is combined with technical efficiency, such that production takes place on the frontier and is optimally balanced with consumers' preferences, the outcome is equivalent to the first-best outcome.

Coordination is one of three main goals of contract design, cf. Bogetoft and Olesen (2004). The other main goals are motivation and minimization of transaction costs. Together, the three goals contribute to the overall goal of maximizing integrated profit, i.e., the sum of profits of all the contracting parties in a production chain context as analyzed by Bogetoft and Olesen. In the context of utility regulation, the overall goal of the regulator would be to maximize social welfare or at least the welfare of end consumers. The three overall goals however need to be balanced since they may conflict. Focusing solely on one objective will come at the cost of assigning a lower priority to the other objectives. The regulator therefore needs to prioritize between the different objectives and must accept trade-offs between them. When prioritizing coordination of production, it may come at the expense of providing strong incentives for the firm to control its costs (the moral hazard problem) and minimizing information rents (the adverse selection problem).

In utility regulation, the problem of adjusting the services provided to the preferences of the end-consumers has historically not been stressed. Instead, demand has been given exogenously and the focus has been to ensure that the fixed demand is fulfilled at lowest possible costs. In fact, many of the existing regulatory benchmarking models do not even consider the final services as the cost drivers. Instead, they use some intermediate products, e.g., the network items acquired and operated with the aim of providing the final services. More recently, however, there has been an interest in the coordination aspect, i.e., in ensuring that utilities deliver the services and qualities that end-consumers value the most, cf. below. To do so, it becomes important to use output-based regulations where costs are linked to the outputs valued by end-users.

2.3. Regulatory examples

Based on the hierarchy of goals for contract design developed by Bogetoft and Olesen (2004), Eskesen (2021) illustrates, by four regulatory examples, how utility regulators have prioritized various goals of contract design in different ways. In the regulation of British electricity and gas networks (RIIO), Scottish Water, and Copenhagen Airport, customers and other stakeholders are involved in the regulatory process thereby creating an opportunity for higher coordination between consumer preferences and production possibilities. In contrast, the regulation of Danish electricity distribution companies is an example of a revenue cap regulation where the model for calculating allowed revenues does not directly depend on consumer preferences. Demand is considered to be fixed and company or consumer specific circumstances, which are not directly accounted for in the legislation, cannot be taken into account. Coordination of production, therefore, seems to be less of a priority in this case.

According to Joskow (2014), as incentive regulation has evolved, focus has shifted from reducing operating costs to investment and various dimensions of service quality. In the UK, this change in focus can be seen in a change away from an RPI-X regulation to the RIIO model in 2010, as the existing RPI-X regulation was not considered robust enough to handle future challenges and was focused more on economic efficiency than on outputs that are valuable to consumers (Ofgem, 2009). Among other issues, the regulator (Ofgem) was worried that RPI-X might not support the changing nature of energy network services and the associated uncertainty about which investments are necessary in the transition to a low carbon economy. To address these issues, regulation was changed so that consumers and other stakeholders are allowed a greater role in the decision-making process and where allowed revenues of companies partly depend on their performance on a number of outputs. The companies set out their initiatives for the coming period in business plans and submit these to the regulator for assessment. The business plans must demonstrate how they are influenced by stakeholder engagement and thus provide the basis for a higher coordination of production, where outcomes reflect a higher alignment between stakeholders' preferences and companies' production possibilities. At the same time, it may be challenging to assess the cost-efficiency of proposed initiatives if the associated costs cannot be compared to historical costs or to the costs of other companies' business plans. In this way, prioritizing coordination of production may come at the cost of providing companies with information rent.

The regulation of Scottish Water and Copenhagen Airport is based on a direct negotiation between the regulated companies and their customers (or customer representatives). This facilitates coordination of production but private information, for example about costs, may impact negotiations and, thus, leave companies with more bargaining power. Therefore, in the regulation of Scottish Water, the regulator supports the customer representatives in the Customer Forum in negotiations by issuing guidance on the most material parameters in price setting, e.g., on the scope for future efficiency improvements. However, the regulator's assessment of efficient costs is also challenged by private information, for example if new developments in the sector lead to new initiatives such that costs cannot easily be compared to historical costs.

[3] See for example Bogetoft (2012).

In the regulation of Copenhagen Airport, the regulator can participate as an observer in the negotiations between the airport and airlines or decide to enter into negotiations as a mediator, if needed. Moreover, the regulator can order the parties to present whichever documentation and information the authority may find necessary to ensure transparency during negotiations. It has, however, proved difficult to ensure equality and transparency in negotiations. This has led to adjustments in the regulation from year 2018 with the aim of increasing equality and transparency (Ministry of Transport, Building, and Housing, 2017; Danish Transport, Construction and Housing Authority, 2017). In the revenue cap regulation of Danish electricity distribution companies, allowed revenues are calculated on the basis of historical costs. Within the regulatory period, the revenue cap is, however, subject to a number of different adjustments that reflect changes in conditions beyond the companies' control. Adjustments can be made either on application from the companies or by an automatic link to a price index or activity indicators (Danish Ministry of Energy, Utilities and Climate, 2018). Allowed revenue is generally mechanically determined and governed by a legislation that specifies the conditions for all adjustments. Moreover, a benchmarking model determines the relative efficiency of companies that results in efficiency requirements to the least efficient companies. The companies may, therefore, make operation and investment decisions based on the expected effect on the revenue cap and their relative efficiency. In this case, costs may be easier to compare, both over time and across companies, reducing opportunities for information rent, but the decisions made by companies may not reflect coordination with consumers and other stakeholders.

3. Model

We consider a regulator (the principal) negotiating with two utilities (the agents) on the production of different services and the remuneration for providing these services. Services could, for example, encompass the duration of customer interruptions, grid capacity, time to connect new demand and the establishment of new generation nodes. Since we will assign utilities to different service combinations, it is most natural to think of the setting as one of output-based regulations.[4] Here, we limit the scope to the mix of two different services, y_1 and y_2. We let $y^i = (y^i_1, y^i_2) \in \mathbb{R}^2_+$ be the observed service profile produced by agent i.

We might think of the underlying production possibilities as being defined by a cost function $\phi : \mathbb{R}^2_+ \to \mathbb{R}_+$ and let c_i be the underlying minimal costs of producing $y^i = (y^i_1, y^i_2)$, i.e.,

$$c^i = \phi(y^i_1, y^i_2), \quad i = 1, 2 \tag{1}$$

Here, we have assumed that the agents have the same cost function. It is therefore clear that relative performance evaluation is meaningful. Of course, as is well-known from the literature, relative performance evaluation is relevant more generally when there is some correlation between the costs faced by the two agents, e.g., if they are both affected by a common price index.

We will assume that the principal does not know ϕ. The principal only knows that costs are increasing weakly in the services produced.

The agents are better informed. We assume that they do not know ϕ in all details,[5] but they know costs locally. That is, if the principal asks an agent to produce y, the agent can determine $\phi(y)$. This seems to be a reasonable assumption in applications. We will ignore the possible search costs of finding $\phi(y)$.

[4] In many regulations in Europe, the benchmarking cost model uses intermediate outputs like km of lines, number of transformers, etc. as cost drivers. There can be many practical reasons for this, but it is obvious that the end-users typically do not assign values to these intermediate outputs. End-consumers are not concerned with how the services are produced, but rather with the actual services delivered.

[5] If the agents know ϕ and they can costlessly communicate the full details of ϕ, one can incentivize them to "freely" reveal this information, e.g., by introducing a very harsh punishment should their cost function messages deviate.

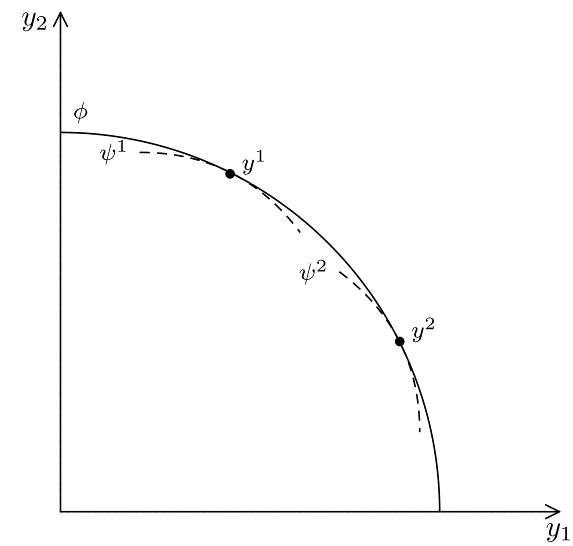

Fig. 1. Envelope of local cost functions.

To formalize the assumption a little more, we might assume that agent i has private information about his type

$$\psi^i \in \Psi^i \tag{2}$$

When the aim is to produce y^i, we might think of ψ^i as a local cost function with $\psi^i(y) \geq \phi(y)\ \forall y$ and $\psi^i(y^i) = \phi(y^i)$. More specifically, we can think of ψ^i as the cost function of the technology that leads to the lowest cost of producing y^i. In this setting, we can think of ϕ as the lower envelope of the local technologies Ψ, i.e.,

$$\phi(y) = \min_{\psi^i \in \Psi^i} \psi^i(y) \quad \forall y \in \mathbb{R}^2_+,\ \forall i \tag{3}$$

This is similar to the idea of long-run cost curves being a lower envelope of short-run cost curves. An illustration is given in Fig. 1.

We let $x^i \in \mathbb{R}_+$ be the observed cost of agent i. The costs may not necessarily be the minimal costs $\phi(y^i)$ necessary to produce the services y^i since the agent may be inefficient or try to extract information rents as on-the-job consumption, e.g., as perks. To model this, we assume that the regulator can observe and verify the output y^i and the incurred costs x^i, but the regulator cannot observe the minimal costs $\phi(y^i)$ of producing y^i.

To formalize this, we assume that the actual costs x^i of agent i may include slack, $s^i \geq 0$, such that

$$x^i = \phi(y^i_1, y^i_2) + s^i, \quad i = 1, 2. \tag{4}$$

Slack s^i makes it easier for agent i to operate. We can model this in the simplest possible way by assuming that slack comes with a monetary equivalent value of $\rho^i s^i$, $i = 1, 2$ to agent i. Here, $\rho^i \in [0, 1)$ is the marginal value of slack compared to monetary profit. If $\rho = 0.6$, it means that \$1 spent on slack gives the same value to agent i as \$0.6 profit. More generally, we can assume that the agents' utility is increasing in profits and slack and that the marginal utility of profit exceeds the marginal utility of slack. For more on such models, see Bogetoft (1997, 2000).

We also assume that the two utilities serve different consumers. The agents may, for example, operate in separate geographic areas with associated consumers. The consumer groups have different preferences. We let

$$u^i = u^i(y^i_1, y^i_2), \quad i = 1, 2 \tag{5}$$

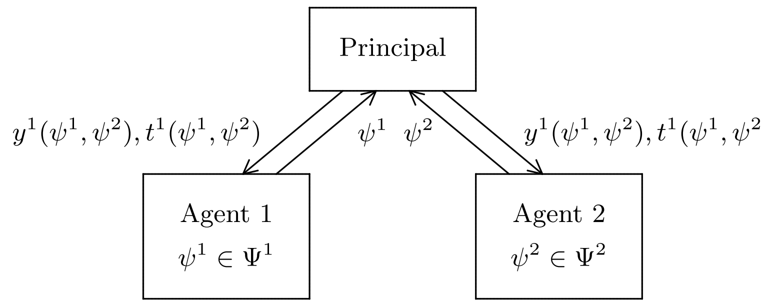

Fig. 2. Revelation game.

be the gains (in monetary equivalents) to consumer group i from receiving services (y_1^i, y_2^i).

Lastly, we let the consumers' payments for the services received be denoted as the transfers

$$t^i, \quad i = 1,2 \tag{6}$$

The transfers will depend on the contractable information. We will first consider a revelation game where the transfers depend on the agents private information, $t^i(\psi^1, \psi^2)$. Next, we turn to a more specific case, more in line with traditional regulation. Here, the transfer depends on the contractible information ex post, i.e., the realized costs of both agents and the service profiles they provide, $t^i(x^1, x^2, y^1, y^2)$. The transfer scheme is the core of the regulation. It defines how the agents are rewarded as a function of their observable outcomes.

The objective of the end-consumers is to maximize their net value, i.e., their utility from the services provided minus their payment for those services:

$$V^i = u^i - t^i, \quad i = 1,2. \tag{7}$$

Since the regulator aims to serve as a proxy-buyer, the regulator seeks to maximize the sum of these values:

$$V^1 + V^2 \tag{8}$$

The agents, on the other hand, seek to maximize the transfer received minus the cost of providing the services plus the possible gains from operating with slack:

$$W^i = t^i - x^i + \rho^i s^i, \quad i = 1,2 \tag{9}$$

Now, to summarize the general setting, we can use a revelation game as illustrated in Fig. 2.

The idea is that the agents get signals ψ^i, $i = 1,2$, about their cost types and send this information to the principal. The principal then decides on the production plans to be implemented, y^i, $i = 1,2$, as well as the transfers $t^i, i = 1,2$. The production and transfer plans are therefore mappings, $y^i(\cdot) : \Psi = \Psi^1 \times \Psi^2 \to \mathbb{R}_+^2, i = 1,2$, and $t^i(\cdot) : \Psi = \Psi^1 \times \Psi^2 \to \mathbb{R}_+$, $i = 1,2$.

From the revelation principle, we know that any solution to the principal's problem can also be implemented as a direct revelation game where the agents have incentives to reveal their true types. We can therefore formulate the principal's general problem as a mathematical program,

$$\max_{t^1,t^2,y^1,y^2} E_{\psi^1,\psi^2}\left[\sum_{i=1}^{2} V^i(y^i(\psi), t^i(\psi))\right] = E_{\psi^1,\psi^2}\left[\sum_{i=1}^{2}(u^i(y^i(\psi)) - t^i(\psi))\right]$$

$$\begin{aligned}
\text{s.t.}\quad & t^i(\psi) - \psi^i(y^i(\psi)) && \geq && 0 \\
& \quad \forall \psi \in \Psi^1 \times \Psi^2\ \forall i && && (IR) \\
& t^i(\psi) - \psi^i(y^i(\psi)) && \geq && t^i(\tilde{\psi}^i, \psi^{-i}) - \psi^i(y^i(\tilde{\psi}^i, \psi^{-i})) \\
& \quad \forall \psi \in \Psi^1 \times \Psi^2, \tilde{\psi}^i \in \Psi^i\ \forall i && && (IC) \\
& y^i(\psi) \in \mathbb{R}_+^2, && t^i(\psi) \in \mathbb{R} \\
& \quad \forall \psi \in \Psi^1 \times \Psi^2\ \forall i
\end{aligned}$$

where we stick to the common notation of ignoring the superscript when covering both agents, e.g., $\psi = (\psi^1, \psi^2)$ and where superscript $-i$ refers to the agent who is not i. Note that we have simplified the individual rationality (IR) and the incentive compatibility (IC) constraints here by using the fact that $\rho < 1$, i.e., the agents will not introduce slack when payments are given and independent of the realized costs x.

The principal's objective is to choose production plans and transfer schemes that maximize the expected net utility to the end consumers subject to incentive compatibility (IC) constraints, ensuring that the agents will reveal their true private information instead of manipulating their private information, ψ^i, and instead send a message, $\tilde{\psi}^i$. Also, we include individual rationality (IR) constraints to ensure that the agents will participate. In the regulation of critical infrastructure, the regulator naturally wants to avoid disruption of services. Another way to express this is to say that the principal cannot reduce information rents by rationing away certain agent types.[6]

Solving the full revelation game is complicated and requires more specific assumptions about the technology. Antle and Bogetoft (2019) investigate a related problem under the assumption that the underlying cost function is linear but the principal has limited information about the marginal costs of the two outputs. The principal only knows that $cy^0 \leq x^0$. They show that the optimal solutions tend to be biased toward the historical plan, y^0. In the example below, we will make less restrictive assumptions about the underlying cost function.

Another complication is the choice of optimal production plans. Antle and Bogetoft (2019) did not fully integrate the choice of production plan; they simply explored the role of the production plan to be implemented and showed that implementation becomes more costly the greater the new plan deviates from the historical plan. In the following, we will analyze a more specific numerical problem and solve the contract design problem for different values of the production mixes. We will hereby show how the choice of service mixes affects the agents and the end-consumers and determine the optimal production plans. In particular, we will hereby illustrate the extra costs of implementing differentiated production plans.

When the production plans (y^1, y^2) are fixed, the principal's problem reduces to the design of transfer schemes that are individually rational and make it optimal for the agents to minimize the costs of producing the outputs. We can illustrate this as the simple relative performance setup in Fig. 3.

Here, the principal initially instructs the agents what to produce. Next, the agents decide how to produce the outputs, including whether or not to introduce slack. The resulting costs are observed (and verifiable by the principal) and based hereon, the final transfers are made. The agents know the transfer plans when they select their cost levels. When production plans are fixed, the principal's problem reduces to one of minimizing the cost of implementing these plans. Again, by the

[6] When rationing is possible, the analysis becomes more complicated, but the qualitative insight about information rents increasing in the product differentiation, is not changed. For an analysis with rationing, see Antle and Bogetoft (2019).

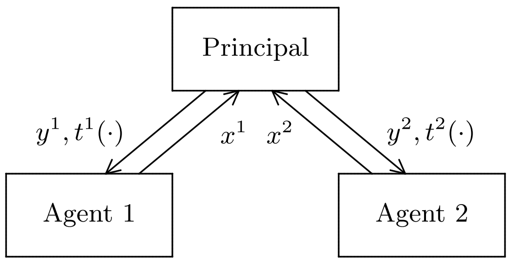

Fig. 3. Relative performance evaluation approach.

revelation principle, we might restrict attention to transfer schemes where the agents are given incentives to report their costs truthfully. An agent i may deviate from revealing his true minimal costs c^i by adding slack leading to realized costs x^i. The corresponding mathematical program is, therefore

$$\begin{aligned}
&\min_{t^1,t^2} E_{c^1,c^2}\left[\sum_{i=1}^{2} t^i(y,c^1,c^2)\right] \\
&\text{s.t. } t^i(y,c)-c^i && \geq 0 \\
&\quad \forall c \in C^1 \times C^2 \ \ \forall i && (IR) \\
&\quad t^i(y,c)-c^i && \geq t^i(y,x^i,c^{-i}) - x^i + \rho(x^i - c^i) \\
&\quad \forall c \in C^1 \times C^2, x^i \in C^i, x^i \geq c^i \ \ \forall i && (IC) \\
&\quad t^i(c) \in \mathbb{R} \\
&\quad \forall c \in C^1 \times C^2 \ \forall i
\end{aligned}$$

where $C^i = \{\psi^i(y^i) \mid \psi^i \in \Psi^i\}$, $i = 1,2$, is the set of possible cost levels for agent i when the production plan is fixed at y^i.

4. A numerical illustration

To illustrate the principal's challenge of balancing the costs and benefits of adjusting production to end-users' preferences, let us consider some numerical examples.

Specifically, we will assume that the cost of producing (y_1, y_2) is

$$c = \phi(y_1,y_2) = \begin{cases} 100\sqrt{y_1^2+y_2^2} & \text{if } y_1^2+y_2^2 \leq 1 \\ \infty & \text{otherwise} \end{cases} \tag{10}$$

We see that the cost function is an increasing, free-disposable function that satisfies constant returns to scale[7] on the positive quadrant of the (closed) unit disk, and that it is not possible to produce outside this area.[8] We see also that the cost is 100 on the production possibility frontier.

Now, as above, we will assume that the principal does not know this function. He only knows that the underlying cost function is an increasing, free-disposable and constant returns to scale cost function on the unit disk and that production is not possible outside the disk. We also assume that the agents have this information. In addition, the agents can determine the costs of a specific production plan they may be asked to implement.

Consumers' preferences are first assumed to be given by Cobb–Douglas utilities:

$$u^1(y_1,y_2) = K y_1^{1/5} y_2^{4/5} \tag{11}$$

$$u^2(y_1,y_2) = K y_1^{4/5} y_2^{1/5} \tag{12}$$

where K is a constant. Consumer group 1 thus values y_2 higher than y_1 while consumer group 2 values y_1 higher than y_2. We let $K = 300$ in our base case, but any $K \geq 100\sqrt{2}$ can be used in our calculations.[9] To illustrate the importance of the utilities generated compared to the cost of delivery, we will also consider the case of $K = 600$.

4.1. *First-best perfect information*

As a benchmark, suppose first that the regulator has perfect information about the underlying cost function and consumers' preferences.

In this case, the agents cannot manipulate the description of costs. The IC constraint is therefore not relevant. Leaving any rents to the agents also increases the costs to the principal. Hence, the IR constraint must be binding. In the first-best solution, the agents are, therefore, simply paid the minimal production costs. In particular, the principal shall not allow any slack since slack is a cost inefficient way for the principal to reward the agent.

The regulator's optimization problem in the case of perfect information separates into two subproblems, one for each of the agents:

$$\max_{y_1,y_2} 300 y_1^{1/5} y_2^{4/5} - 100\sqrt{y_1^2+y_2^2} \tag{13}$$

$$\max_{y_1,y_2} 300 y_1^{4/5} y_2^{1/5} - 100\sqrt{y_1^2+y_2^2} \tag{14}$$

The first-order conditions imply for consumer 1 that $2y_1 = y_2$ and for consumer 2 that $y_1 = 2y_2$. Substituting back into the production function, we obtain the following first-best outcomes, which are illustrated in Fig. 4.

$$\begin{aligned} y^1 &= (\sqrt{1/5}, \sqrt{4/5}) \\ y^2 &= (\sqrt{4/5}, \sqrt{1/5}) \end{aligned} \tag{15}$$

These are the service levels that maximize consumers' utility within the production possibilities set. The corresponding utility levels are $u^1 = 300\left(\sqrt{1/5}\right)^{1/5}\left(\sqrt{4/5}\right)^{4/5} \approx 234$ and $u2 = 300\left(\sqrt{4/5}\right)^{4/5}\left(\sqrt{1/5}\right)^{1/5} \approx 234$. In the first-best solution, the parties coordinate optimally, i.e., the produced services provide each consumer (group) with the highest possible utility, given the available technology.

4.2. *Second-best*

Since the regulator only knows that the cost function is increasing, freely disposable and has constant returns to scale on the unit disk, the regulator has to rely on the relative performance evaluation to determine reasonable transfers.

By the revelation principle, we can assume that the agents must have incentives to reveal the true costs. The agents will only do so if they are not penalized for telling the truth. Assume now that agent 2 has produced y^2 as in Fig. 5 and reported the true costs x^2. In this case, the principal knows with certainty that all production plans to the south west of y^2 are also feasible at a cost of x^2. Furthermore, he knows

[7] The assumption of constant returns to scale is not conceptually important but it simplifies calculations and hereby makes it easier to following the logic while reading the paper. If, for example, the agents faced increasing returns to scale (which in many cases is why they are regulated to begin with), and if we know the returns to scale structure, e.g., $\phi(t(y_1,y_2)) = t^\alpha \phi(y_1,y_2)$, where $\alpha < 1$ in the case of increasing returns to scale, we could redo all calculations by adjusting the payments accordingly. Instead of $t_1 = \frac{OD}{OC}x^2$ in Eq. (17) for example, we would instead get $t_1 = (\frac{OD}{OC})^\alpha x^2$.

[8] We could alternatively have assumed that the cost function was quadratic, e.g., $100(y_1^2+y_2^2)$ but this would make calculations more complex since we would have to not only find the optimal mix of services, also the optimal length of the service vector. This means that we would have to look not only at the marginal rates of substitution between the products but also at the directional derivatives of the utility and cost functions.

[9] The condition $K \geq 100\sqrt{2}$ ensures that the directional distance in the direction of all the points on the unit circle we investigate is at least 100 and, hence, that it is optimal under perfect information to produce at the unit circle instead of inside the unit circle.

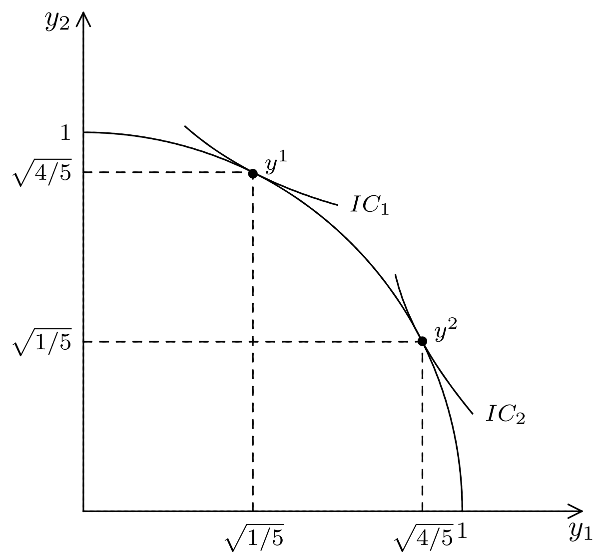

Fig. 4. The first best solution.

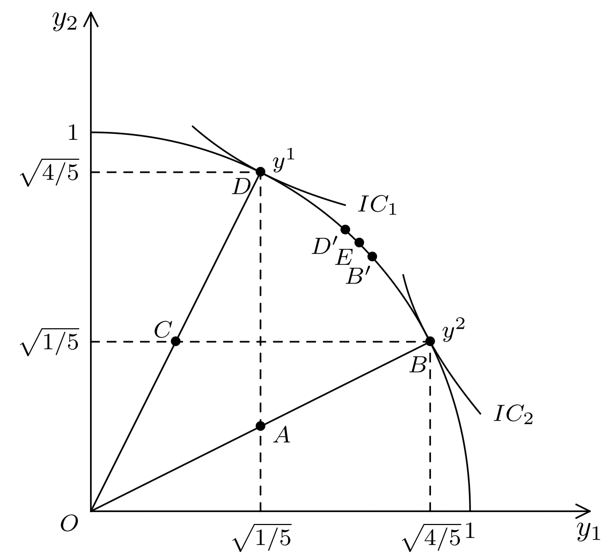

Fig. 5. Implementation of first-best solutions in second-best world.

that the cost function is increasing and has constant returns to scale on the unit disk. A worst-case cost function from the point of view of the principal; i.e., the highest cost function consistent with the available information, is, therefore, a cost function with x^2 iso-quant defined by the dashed lines originating from y^2 in Fig. 5. This cost function can formally be defined as follows:

$$\tilde{\phi}(y) = x^2 \max\{\frac{y_1}{y_1^2}, \frac{y_2}{y_2^2}\} \text{ for } (y_1)^2 + (y_2)^2 \leq 1 \tag{16}$$

If this were actually the true cost function, the cost of the other production plan, y^1, in Fig. 5 would be $\frac{OD}{OC}x^2$ where OD is the distance between the origin O and the point D, and OC similarly is the distance of O to D. By the no-rationing, individual rationality constraint, the principal will therefore have to pay at least $\frac{OD}{OC}x^2$. Also, since this is independent of the actual cost of agent 1, x^1, it makes it incentive compatible to reveal the cost of y^1, namely $x^1 = \phi(y^1)$. We can of course make similar inference about the worst-case cost function based on (y^1, x^1) information and use this to determine the compensation of agent 2. In summary, we therefore must have the following:

$$t_1 = \frac{OD}{OC}x^2 \tag{17}$$

$$t_2 = \frac{OB}{OA}x^1 \tag{18}$$

In the optimal compensation plans, an agent is honest since its cost claim does not affect its own payoff. However, as illustrated below, agents earn information rents when their production plans are different from other agents' production plans. This is due to the fact that an agent is compensated on the basis of the worst possible technology from the regulator's point of view, which is consistent with the information about the other agent. The regulator is left with no other option when the efficiency frontier is unknown to the regulator and when the regulator cannot ration.

Using the same specific values for parameters in the utility function as in Section 4.1, the bundles A and C and the distances, OA and OC, can be computed as follows:

$$A = \left(\sqrt{1/5}, \frac{\sqrt{1/5}}{\sqrt{4/5}}\sqrt{1/5}\right) = \left(\sqrt{1/5}, \sqrt{1/20}\right)$$

$$OA = \sqrt{\left(\sqrt{1/5}\right)^2 + \left(\sqrt{1/20}\right)^2} = \sqrt{1/4} = \tfrac{1}{2}$$

$$C = \left(\frac{\sqrt{1/5}}{\sqrt{4/5}}\sqrt{1/5}, \sqrt{1/5}\right) = \left(\sqrt{1/20}, \sqrt{1/5}\right)$$

$$OC = \sqrt{\left(\sqrt{1/20}\right)^2 + \left(\sqrt{1/5}\right)^2} = \sqrt{1/4} = \tfrac{1}{2}$$

When $x^1 = x^2 = 100$, the payments and information rents can be computed as follows:

Payment to agent 1 :	$t^1 = \frac{OD}{OC}x^2 = \frac{1}{1/2}100 = 200$
Payment to agent 2 :	$t^2 = \frac{OB}{OA}x^1 = \frac{1}{1/2}100 = 200$
Information rents to agent 1 :	$t^1 - c^1 = 200 - 100 = 100$
Information rents to agent 2 :	$t^2 - c^2 = 200 - 100 = 100$

In this case, we have perfect coordination with consumer preferences, but it comes at the cost of providing the companies with information rents.

Alternatively, by choosing service mixes that are closer to each other, we can reduce information rents. For example, as illustrated in Fig. 5, the regulator could ask agent 2 to produce D' instead of D, it could ask agent 1 to produce B' instead of B, or it could ask both agents to produce E.

Table 1 shows the corresponding utilities and information rents of the different service combinations, thereby illustrating the trade-off between service differentiation and information rent. Information rents are minimized at point E, where both agents produce the same service mix but coordination with consumers' preferences is lower than at points (D, B) which is reflected in lower utility levels. However, point E maximizes the total value to consumers, i.e., utility adjusted for the transfer to the companies, $V^i = u^i - t^i$. At points D' and B', coordination is improved compared to E at the cost of increasing information rents. When maximizing the total value to consumers, the optimal second-best solution is for both companies to produce the same bundle corresponding to point E in Fig. 5.

Furthermore, Fig. 6 illustrates the change in consumer surplus as the production bundles deviate from the symmetric production bundle

Table 1
Variation of output mix for $K = 300$.

		First-best	Second-best proposals				
		(D,B)	(D,B)	(E,E)	(B,B)	(D,D)	(D',B')
Payment by agent 1	t^1	100	200	100	100	100	111
Payment by agent 2	t^2	100	200	100	100	100	111
Total payment by agents	$t^1 + t^2$	200	400	200	200	200	221
Profit to agent 1	w^1	0	100	0	0	0	11
Profit to agent 2	w^2	0	100	0	0	0	11
Agents' total profit	$w^1 + w^2$	0	200	0	0	0	21
Consumer 1's utility	u^1	234	234	212	154	234	218
Consumer 2's utility	u^2	234	234	212	234	154	218
Consumers' total utility	$u^1 + u^2$	467	467	424	388	388	436
Net value to consumer 1	V^1	134	34	112	54	134	108
Net value to consumer 2	V^2	134	34	112	134	54	108
Total net value to consumers	$V^1 + V^2$	267	67	224*	188	188	215

Notes: (*i*) D = $(\sqrt{1/5}, \sqrt{4/5})$, B = $(\sqrt{4/5}, \sqrt{1/5})$, E = $(\sqrt{1/2}, \sqrt{1/2})$, D' = $(\sqrt{4/9}, \sqrt{5/9})$, B' = $(\sqrt{5/9}, \sqrt{4/9})$, $u^1 = K y_1^{1/5} y_2^{4/5}$ and $u^2 = K y_1^{4/5} y_2^{1/5}$, where $K = 300$.

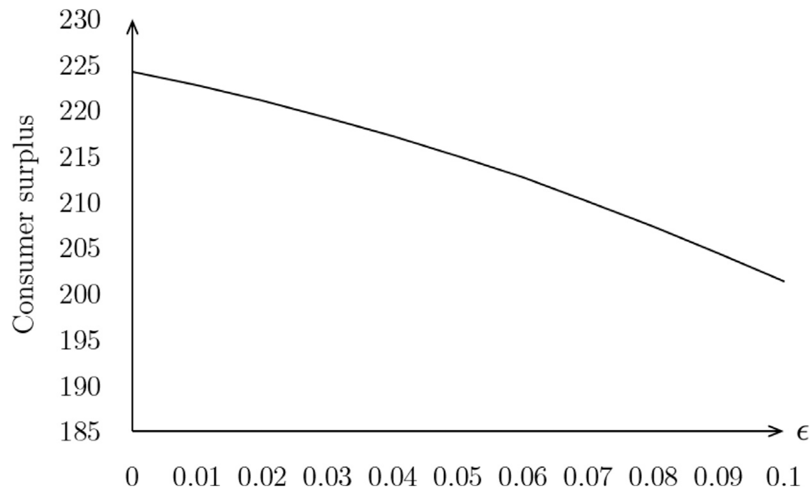

Fig. 6. Consumer surplus as a function of the deviation ϵ from (E, E) for $K = 300$.
Note: Fig. 6 illustrates the level of consumer surplus as the production plans diverge from $(E, E) = (\sqrt{1/2}, \sqrt{1/2})$ in the direction of the first-best outcomes: $y^1 = (\sqrt{1/2 - \epsilon}, \sqrt{1 - (1/2 - \epsilon)})$ and $y^2 = (\sqrt{1/2 + \epsilon}, \sqrt{1 - (1/2 + \epsilon)})$. The first-best outcomes are $y^1 = (\sqrt{1/5}, \sqrt{4/5})$ and $y^2 = (\sqrt{4/5}, \sqrt{1/5})$, which corresponds to $\epsilon = 0.3$.

(E, E). Fig. 6 shows that consumer surplus is strictly decreasing in the deviation from (E, E).

Part of the reason why it is not worthwhile to deviate from (E, E) in this particular example is the magnitude of consumers' utility as reflected by $K = 300$. Higher values of K increase the weight on consumers' utility relative to the payment to the companies, which can make it worthwhile to deviate from (E, E). For example, $K = 600$ makes it optimal to deviate from (E, E) and instead let the companies produce (D', B'). This case is illustrated in Table 2. Likewise, Fig. 7 illustrates how consumers' surplus increases as the production plans moves from (E, E) toward (D', B') and hereafter decreases.

5. Extensions

In Section 4, we have analyzed the outcome of a specific regulatory setting. Regulatory practices and settings, however, differ considerably. In this Section, we investigate how some obvious variations in the regulatory setting may impact the outcome in general and the trade-off between service differentiation and information rents in particular.

5.1. Yardstick competition

Above we have made a series of assumptions about the class of possible cost functions and the information that the principal and agents have access to. In this setting, we argued that a version of yardstick competition is optimal. The yardstick scheme that we have used is a so-called DEA-based yardstick competition, cf. Bogetoft (1997, 2000). It is the optimal regulation in some situations where rationing is not possible and where there is considerable initial uncertainty about the class of possible cost functions, e.g., when we only know that the cost of the service provision is an increasing and free disposable function of the service levels.

More generally, yardstick competition, where a firm's allowed revenue is determined from the cost of other firms, is recognized for providing strong incentives for cost reductions; allowed revenue does not depend on the firm's own costs so the firms can profit from beating the standard that is determined by the costs of other firms. In this way, the costs of all firms will converge toward the efficient cost frontier. Shleifer (1985) shows that yardstick competition, as a mechanism to regulate identical firms or heterogenous firms with observable differences, can deliver first-best outcomes in some settings. Importantly, accounting data on costs is sufficient to achieve efficiency, so the regulator's limited knowledge about true costs does not lead to a distortion of outcomes away from first-best outcomes:

> "By relating the utility's price to the costs of firms identical to it, the regulator can force firms serving different markets effectively to compete. If a firm reduces costs when its twin firms do not, it

Table 2
Variation of output mix for $K = 600$.

		First-best	Second-best proposals				
		(D,B)	(D,B)	(E,E)	(B,B)	(D,D)	(D',B')
Payment to agent 1	t^1	100	200	100	100	100	111
Payment to agent 2	t^2	100	200	100	100	100	111
Total payment to agents	$t^1 + t^2$	200	400	200	200	200	221
Profit to agent 1	w^1	0	100	0	0	0	11
Profit to agent 2	w^2	0	100	0	0	0	11
Agents' total profit	$w^1 + w^2$	0	200	0	0	0	21
Consumer 1's utility	u^1	467	467	424	308	467	436
Consumer 2's utility	u^2	467	467	424	467	308	436
Consumers' total utility	$u^1 + u^2$	934	934	849	775	775	872
Net value to consumer 1	V^1	367	267	324	208	367	326
Net value to consumer 2	V^2	367	267	324	367	208	326
Total net value to consumers	$V^1 + V^2$	734	534	649	575	575	651*

Note: D = $(\sqrt{1/5}, \sqrt{4/5})$, B = $(\sqrt{4/5}, \sqrt{1/5})$, E = $(\sqrt{1/2}, \sqrt{1/2})$, D' = $(\sqrt{4/9}, \sqrt{5/9})$, B' = $(\sqrt{5/9}, \sqrt{4/9})$, $u^1 = K y_1^{1/5} y_2^{4/5}$ and $u^2 = K y_1^{4/5} y_2^{1/5}$, where $K = 600$.

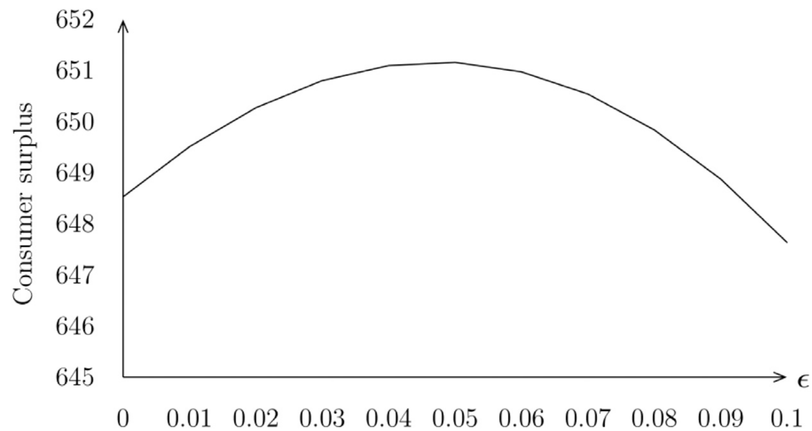

Fig. 7. Consumer surplus as a function of the deviation ϵ from (E, E) for $K = 600$.
Note: Fig. 7 illustrates the level of consumer surplus as the production plans diverge from $(E, E) = (\sqrt{1/2}, \sqrt{1/2})$ in the direction of the first-best outcomes: $y^1 = \left(\sqrt{1/2 - \epsilon}, \sqrt{1 - (1/2 - \epsilon)}\right)$ and $y^2 = \left(\sqrt{1/2 + \epsilon}, \sqrt{1 - (1/2 + \epsilon)}\right)$. The first-best outcomes are $y^1 = \left(\sqrt{1/5}, \sqrt{4/5}\right)$ and $y^2 = \left(\sqrt{4/5}, \sqrt{1/5}\right)$, which corresponds to $\epsilon = 0.3$.

profits; if it fails to reduce costs when other firms do, it incurs a loss. To use this scheme, the regulator does not need to know the cost reduction technology; the accounting data suffice to achieve efficiency." (Shleifer, 1985, p. 320)

However, the Shleifer (1985) result is conditional on the regulator committing to letting firms go bankrupt if they choose inefficient cost levels. In practice, however, regulators are usually not prepared to let firms go bankrupt.

Many regulators adopt a hybrid of different incentive schemes that include yardstick competition (Joskow, 2014). For example, the regulation of Danish electricity distribution companies is based on a revenue cap regulation, where efficiency requirements are determined using a benchmarking model. In this case, a firm's allowed revenue depends on its historical costs and investments as well as the imposed efficiency requirements. Historical costs are permitted to increase with inflation, activity levels, etc., and the efficiency requirements reduce the allowed costs. In contrast to a 'pure' yardstick regulation, allowed revenue is thus highly dependent on the utility's own historical cost. The benchmarking-based efficiency requirements provide incentives for the utilities to move toward the best practice minimal cost frontier and to reward utilities on the frontier. A utility will benefit from high efficiency levels and it will suffer from being inefficient relative to other utilities. Since a yardstick competition would provide even stronger incentives for cost reduction, we have used this mechanism to illustrate the trade-off between information rents and service differentiation. Other mechanisms that more accurately reflect current regulatory practices would likely be associated with higher information rents. In this way, by having analyzed a yardstick competition setting, we have provided conservative estimates of the distortions in service differentiation that are necessary to reduce information rents.

5.2. Consumer preferences

We saw above that the magnitude of consumers' utilities relative to the payment, i.e., the K factor, has a considerable impact on whether it is worthwhile to differentiate productions plans, cf. Figs. 6 and 7.

The distance between the two groups' utility maximizing output combinations is also important. The more similar the preferred service combinations are to each other, the more comparable are the utilities. The benchmarking is therefore more powerful and the easier it is for the regulator to reduce information rents. If utilities produce exactly the same service mix, we can avoid information rents altogether. On the other hand, if the different consumer groups prefer very different sets of services in a first-best context, it will be more costly to match consumer preferences.

Another factor that affects the solution is the curvature of the indifference curves. More curved indifference curves would lead to a greater loss of utility when deviating from the first-best outcome (D, B).

To illustrate this, let us now assume that consumers' preferences can be represented by Leontief utility functions of the following form:

$$u^1(y_1, y_2) = K \min\left(2y_1, y_2\right) \tag{19}$$

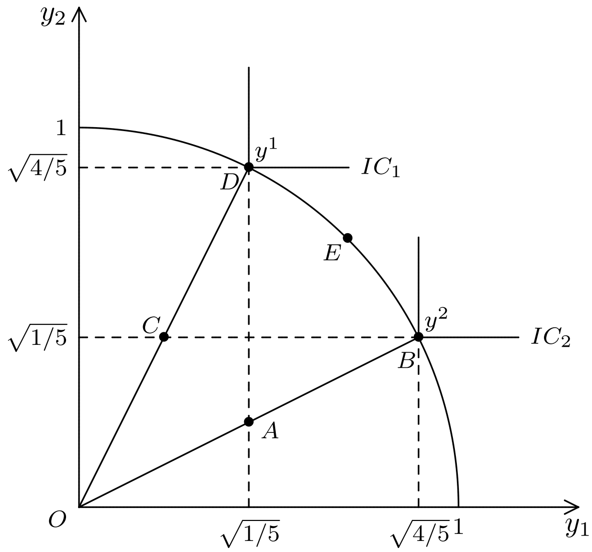

Fig. 8. Leontief preferences.

$$u2(y_1, y_2) = K \min\left(y_1, 2y_2\right) \tag{20}$$

The indifference curves for the utility functions are depicted in Fig. 8. The consumers' utility is maximized when the optimal production bundles satisfy $2y_1 = y_2$ for consumer 1 and $y_1 = 2y_2$ for consumer 2. In this case, the first-best production bundles are similar to the previous case of Cobb–Douglas utility functions as illustrated in Fig. 8. Using a second-best incentive scheme similar to that in the previous Section, it is no longer optimal for the regulator to let the two agents produce identical production bundles for $K = 300$. As illustrated in Fig. 9, consumer surplus is no longer strictly decreasing, as the service mixes move from the symmetrical bundle (E, E) toward the specialized bundle (D, B). Specifically, consumer surplus is maximized[10] when agent 1's production is slightly biased toward D and agent 2's production is slightly biased toward B:

$$y^1_{SB} = (\sqrt{0.48}, \sqrt{0.52}) \tag{21}$$

$$y^2_{SB} = (\sqrt{0.52}, \sqrt{0.48}) \tag{22}$$

Again, increasing K from 300 to 600 makes it more costly to deviate from consumers' preferred bundles. As a result, the optimal production plans are better aligned with consumer preferences:

$$y^1_{SB} = (\sqrt{0.30}, \sqrt{0.70}) \tag{23}$$

$$y^2_{SB} = (\sqrt{0.70}, \sqrt{0.30}) \tag{24}$$

Accordingly, Fig. 10 illustrates that consumer surplus is maximized at a much larger deviation from (E, E).

We have seen above that when consumers are less willing to substitute between the services, as modeled for example by the move to Leontief preferences, information rents increase.

As a small aside, we may note that the information rent also depends on the marginal rate of technical substitution. A case of a linear technology is shown in Fig. 11. To implement the first-best service mixes in this case, the information rents will have to be 400–100, i.e., 300. That is, the information rent is three times higher than the information rents of 100 that we found with the quadratic cost function in Section 4.2. The intuition is also clear. When the production possibilities are linear, there are less cost incentives to choose production mixes that are more similar. When we – in a more curved technology – have to give up more of y_1 to increase y_2, the larger the second output y_2 is, the consumers are less inclined to choose production plans – even in a first-best world – that are too different.

5.3. The number of utilities and service dimensions

Information rents are also affected by the number of utilities. By having only two utilities in our example, we have illustrated the worst-case scenario with respect to the number of utilities. A higher number of comparable utilities would inevitably reduce information rents as the distance between production plans gets reduced. Utilities that wish to maximize information rents would produce service combinations that are as different from each other as possible. This is related to the conclusions in location models, such as Hotelling's linear city model and Salop's circular city model (Hotelling, 1929; Salop, 1979). These models study product differentiation where the difference between products is modeled as the difference between the products' location in a product space.

In Hotelling's linear city model, two firms that sell identical products choose their location along a street where consumers are identical, uniformly distributed, and face transportation costs. If consumers' transportation costs are quadratic, the two firms will locate at the opposite extremes of the city, i.e., with maximum differentiation (d' Aspremont et al., 1979). There are two underlying effects taking place. On one hand, there is an incentive for firms to reduce the distance to the other firm to increase their market share. On the other hand, as a firm gets closer to its competitor, price competition intensifies and this will incentivize product differentiation. The second effect dominates the first effect if consumers' transportation costs are quadratic. In Salop's circular city model, consumers are uniformly distributed on a circle and a number of firms simultaneously choose whether or not to enter the market. Entry is associated with a fixed cost. The entering firms locate themselves equidistant from each other on the circle. The model shows that firms will enter as long as they get a positive profit, i.e., until the margin that they can charge above marginal cost will not cover the fixed cost of entry.

With natural monopolies, there is no market share effect as that in Hotelling's model, since the utilities operate in separate geographic markets so their market shares are largely fixed. Utilities, therefore, have incentives to differentiate their services from the services of other utilities since this limits comparability and, therefore, the power of relative performance evaluation. Nevertheless, profits will decrease with the number of utilities similarly to the circular city model due to the yardstick remuneration. At some point, when the number of utilities is large enough, information rents will be so small that it is no longer optimal for the regulator to prevent a differentiation of production plans. Even with just four utilities, information rents can be avoided entirely if the four utilities are pairwise similar.

However, the possible rents also depend on the number of service dimensions. We have considered the case of just two service dimensions but, in practice, we could easily observe a higher number. A higher number of service dimensions would increase information rents, given the number of utilities, as the product space expands.

Overall, information rents are therefore highly dependent on the prevailing setting that is characterized by a number of factors, including: (i) the number of utilities, where a higher number reduces information rents, (ii) the spatial location of utilities, where a shorter distance between utilities reduces information rents, and (iii) the number of dimensions in the product space, where fewer dimensions reduce information rents.

A final remark on the number of utilities can be made with respect to sectors where there is only a single regulated utility and, therefore, no comparable firms. The results carry over to this setting if the cost

[10] Solved numerically using Excel Solver.

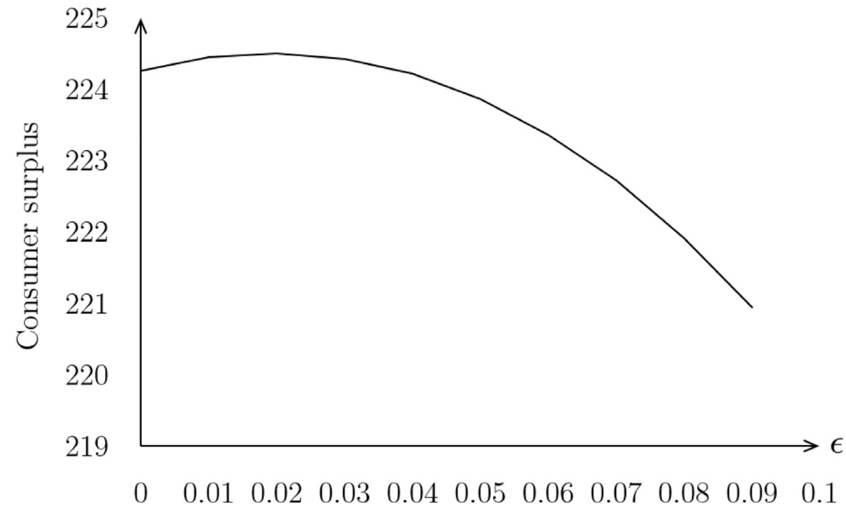

Fig. 9. Consumer surplus as a function of the deviation ϵ from (E, E) for $K = 300$.
Note: Fig. 9 illustrates the level of consumer surplus as the production plans deviate from $(E, E) = (\sqrt{1/2}, \sqrt{1/2})$ in the direction of the first-best outcomes: $y^1 = (\sqrt{1/2-\epsilon}, \sqrt{1-(1/2-\epsilon)})$ and $y^2 = (\sqrt{1/2+\epsilon}, \sqrt{1-(1/2+\epsilon)})$. The first-best outcomes are $y^1 = (\sqrt{1/5}, \sqrt{4/5})$ and $y^2 = (\sqrt{4/5}, \sqrt{1/5})$, which correspond to $\epsilon = 0.3$.

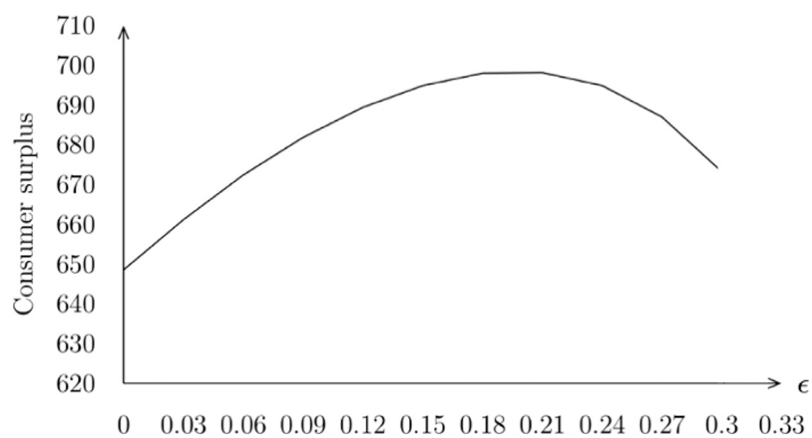

Fig. 10. Consumer surplus as a function of the deviation ϵ from (E, E) for $K = 600$.
Note: Fig. 10 illustrates the level of consumer surplus as the production plans deviate from $(E, E) = (\sqrt{1/2}, \sqrt{1/2})$ in the direction of the first-best outcomes: $y^1 = (\sqrt{1/2-\epsilon}, \sqrt{1-(1/2-\epsilon)})$ and $y^2 = (\sqrt{1/2+\epsilon}, \sqrt{1-(1/2+\epsilon)})$. The first-best outcomes are $y^1 = (\sqrt{1/5}, \sqrt{4/5})$ and $y^2 = (\sqrt{4/5}, \sqrt{1/5})$, which correspond to $\epsilon = 0.3$.

comparison is based on historical data, i.e., longitudinal observations instead of cross-sectional ones. This is the situation studied by Antle and Bogetoft (2019).

We have argued so far that information rents in our model is highly depended on the setting (number of utilities, spatial locations, and number of service features). We might add that the more specific benchmarking procedure also impacts the information rents. In this paper we have used a non-parametric approach based on the idea of minimal extrapolation, free disposability, and constant returns to scale. We might add more assumptions. We might for example add an a priori assumption about convexity leading to the classical CRS DEA model widely used, Charnes et al. (1978). In this case, the information rents will tend to be smaller since we can extrapolate more from fewer data points. Put differently, we can compare firms that are less similar by relying on the extra convexity assumption. If, however, convexity is not a valid assumption, the reduction of information rents comes at the costs of increased bankruptcy risk, i.e., the individual rationality constraints in the regulator's general problem may not always hold. In the context of DEA we may also relate this to the well-known bias problem. DEA models give upwards biased estimated of the necessary costs and the bias is larger the less homogenous the observations are, cf Bogetoft and Otto (2011). The same goes if we add additional assumptions about a particular functional form of the cost function as it is done in parametric approaches. The reduced information rents in this case also comes directly from the a priori assumptions made and there is an increased risk of violating the individual rationality assumptions. Summing up the latter discussion, we can say that benchmarking is less efficient when service profiles are more heterogenous. In turn, this leads to higher information rents. We can try to compensate for this by introducing additional a priori assumptions in our benchmarking efforts, but the added power in this case comes at the costs of increased bankruptcy risk

5.4. Rationing

We have assumed 'no rationing', i.e., the regulator cannot deny production from certain utilities. This assumption is reflected in the participation constraint that ensures that all utilities operate with non-negative profits. If we instead allowed rationing, the regulator could ration away utilities with unfavorable cost structures. This would reduce the utilities' bargaining power and limit information rents. The regulator's gain from rationing does not only come from rationing away inefficient utilities but also from rationing away utilities that may be efficient but where the production plan is markedly different from those of other utilities. In this case, rationing away such utilities may lower the payment to the other utilities. However, a noted above, a

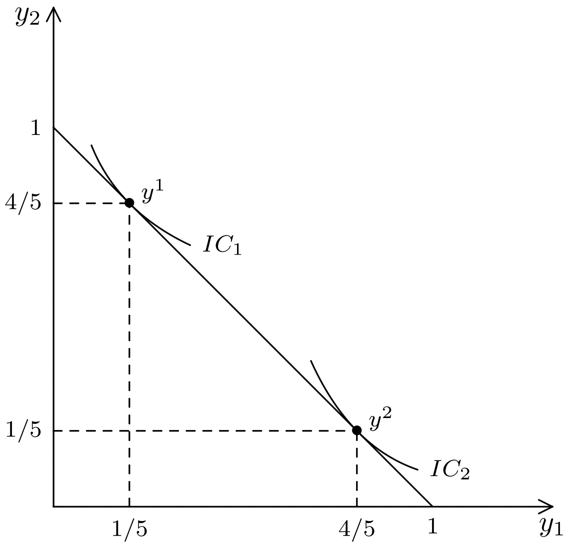

Fig. 11. Linear production possibilities Frontier.

regulator may be reluctant to drive some utilities into bankruptcy to lower payments to other utilities.

5.5. Increased communication and contract menus

We have seen above that service differentiation can come at the cost of paying high information rents because the relative performance evaluation becomes less efficient. Therefore, even if consumers in different regions prefer different service mixes, in some cases, it is optimal to prevent service differentiation, as the associated information rents outweigh the added value to consumers.

In the numerical example, we only allowed limited communication between the principal and the agents. The principal can call upon the agents to produce y^1 and y^2 by offering them contracts that pay according to the yardstick scheme.

In the general case described in the revelation game in Fig. 2, we might imagine the flow of more detailed information. If agent i knows the local cost function ψ^i and is able to inform the principal about it, then it is possible that better outcomes can be achieved.

Instead of thinking of such situations as starting with the agent sending information to the principal, one can also think of such situations as cases where the principal defines a menu of contracts parameterized by $(\psi^1, \psi^2) \in \Psi^1 \times \Psi^2$. This corresponds to the use of contracts, the terms of which for agent 1 depend in part on the choice of contract by agent 2 and vice versa. The contracts would specify what to produce and what the compensation would look like. If agent 2 has chosen a ψ^2 contract, for example, the contract facing agent 1 would be as follows:

> "If you choose contract ψ^1, you will be asked to produce $y^1(\psi^1, \psi^2)$ in exchange for a payment of $t^1(\psi^1, \psi^2)$"

The idea of using menus of contracts is commonly discussed in regulation, although usually in the context of a single agent.

The menu of contracts approach was originally developed by Laffont and Tirole (1986, 1993). They show that the regulator is better off by offering companies a menu of contracts rather than a single contract. In particular, by offering a menu of contracts with different cost-sharing provisions, the regulator can incentivize companies to reveal their type. For example, the menu of contracts can be specified as follows (Joskow, 2014, p 298):

$$R = a + (1 - b)C, \tag{25}$$

where allowed revenue, R, is the sum of a fixed component, a, and a cost-contingent component $(1 - b)C$, where C denotes realized costs, and b is the share of cost carried by the regulated firm. In a fixed price contract (price cap or revenue cap regulation), $a = C^*$, where C^* is the regulator's assessment of the efficient costs of the low cost firm, and $b = 1$; i.e., $R = C^*$. At the other end of the spectrum is a pure cost-of-service regulation, $a = 0$ and $b = 0$, where the allowed revenue is set equal to the firm's realized costs; i.e., $R = C$. A range of different options exists between these two extremes, where $0 < b < 1$ and $0 < a < C^*$.

If the menu is well designed, low cost companies will choose a high-powered contract such as a fixed price contract, where b is closer to 1 and a is closer to C^*, which has strong efficiency incentives. High cost companies will choose a low-powered contract, where a and b are closer to zero, such as a cost-of-service contract with weak efficiency incentives. In contrast, if the regulator only offered a single contract, such as a fixed price contract, the fixed price would have to be high to ensure that high cost companies will accept the contract. The low cost companies can then benefit from claiming to have high costs rather than low costs and earn information rents. Therefore, while a single fixed price contract has the benefit of creating strong efficiency incentives for the high cost companies, it comes at the cost of high information rents to the low cost companies.

However, while the menu of contracts approach has some appealing theoretical properties, it can be difficult to implement in practice. To calculate the optimal menu, the regulator must be able to specify the distribution of the different types of agents, which is not known in practice. However, Rogerson (2003) shows that in some cases, a much simpler menu may be possible to capture a substantial share of the gains that could be achieved with the optimal complex menu. In particular, he considers a menu consisting of two contracts; a cost-reimbursement contract and a fixed price contract, and shows that, under some circumstances, the menu captures at least three-quarters of the gains that could be achieved using the optimal complex menu.

The information quality incentive (IQI) provides an example of the menu of contracts approach used in practice. The IQI mechanism is used in the UK RIIO framework that rewards network companies for submitting expenditure forecasts that are closer to their actual expenditures. However, it also illustrates the difficulties associated with implementing menu of contracts in practice. In particular, Ofgem experienced that network companies systematically forecasted higher expenditures than what they subsequently incurred (Ofgem, 2018).

While there is only limited experience with the explicit use of menu of contracts in practice, Joskow (2014) argues that the regulatory process itself may lead to outcomes that resemble the use of a menu of contracts approach. Specifically, the choice of regulatory framework is often the result of an engagement process involving the regulator, the regulated firm and other stakeholders. In this process, low cost companies will argue in favor of a high-powered contract and high cost companies will argue in favor of a low-powered contract. The process may therefore lead to an outcome similar to the outcome of a formal menu of contracts. Agrell and Bogetoft (2003) study the potential for menu of contracts in the change of the Norwegian regulation of electricity distribution companies. They illustrate how differences in the beliefs firms have about the future cost and demand development can be exploited by offering firms the choice between two possible payment schemes, CPI-X regulation or yardstick regulation. The preferred option for a given firm depends on its historical efficiency, the stipulated efficiency requirement in the CPI-X scheme (X), and the firm's expected productivity gain. The most productive firms will prefer the yardstick regulation, while the least productive firms will prefer the CPI-X regulation. Also, Agrell and Bogetoft (2003) consider a menu of contracts with two different updating frequencies, i.e., different lengths of the regulatory period, to take account of differences in the age profiles of the different networks and the needs for reinvestment.

In practical applications of comparative regulation, it is well established that firms have incentives to emphasize their own 'difference' from the norm in terms of cost structure and level. In many applications, cf. e.g., Agrell and Bogetoft (2007) and Agrell and Bogetoft (2017), we have experienced how this leads to lengthy discussions of relevant cost drivers, returns to scale assumptions, estimation approaches etc. This paper extends that tendency to the 'demand side' and makes clear that regulated firms also have incentives to emphasize the uniqueness of their consumers' preference, and their 'distance' from those in other regions.

This also implies that firms will likely not have incentives to honestly reveal private information about consumer preferences. Rather, our results show that they may have incentives to exaggerate the differences in preferences and possibly to do so in a coordinated effort. One solution to this may be that preference information is collected directly by the regulator or an independent third party.

If the information is only available from the regulated firms and cannot be easily verified, the regulator faces the same problem eliciting the preference information as the regulator faces eliciting cost information. Also, like most comparative regulations face the risk of the firms colluding to exaggerate costs, the firms will have incentives to collude to make the consumer preferences appear more heterogenous than they really are. In theory, the general solution to the problem of eliciting private cost as well as preference information is to construct a revelation game, typically be offering firms cleverly designed menus of contracts as discussed above. The use of such contracts is seldomly seen in applied output-based regulations, cf. above, and the general experience seems to be that the use of complex menus may not lead to the desired outcomes as they are hard to fully understand. Introducing not only private information about the cost structures but about the preference structure as well greatly expands the complexity of such menus. We therefore suggest that in regulatory applications, less ambitious menu-like approaches may be more likely to make improved adaption of production to preferences. Our discussion of cost neutral alternatives below may illustrate the possible use of theoretically sub-optimal but practically useful simplified revelation procedures.

5.6. Cost neutral alternatives

Let us close with a discussion of some of the difficulties of designing a menu of contracts in the setting of this paper, where relative performance evaluations are part of the setup and there are multiple dimensional production plans to consider. To do so, we can consider the idea of cost-neutral alternatives. Jamasb (2020) and Tobiasson and Jamasb (2016) have suggested a menu of contracts approach where the company can propose a menu of cost-neutral options to consumers. The company would be indifferent between the proposed bundles of services but consumers may value some bundles more highly than others. According to Jamasb (2020) and Tobiasson and Jamasb (2016), this approach could lead to higher customer utility at a given cost level and therefore represents a Pareto improvement. This seems obviously to be the case. Imagine a situation in which an agent is offered t to produce y. The agent may then be asked to also make other alternative proposals such as y^A and y^B for the same payment. If the agent knows of two alternatives y^A and y^B with the same costs as y, i.e., where $\phi(y) = \phi(y^A) = \phi(y^B)$, the agent is certainly willing to share this information and the consumers may benefit if they have preferences more favorable to at least one of these alternatives as in Fig. 12.

Here, the idea of cost-neutral alternatives works well and may lead to Pareto improvements. It works however, because payments, t, are fixed.

Imagine that we try to reduce the payments using relative performance evaluations as above. This situation is illustrated in Fig. 13. In this case, agent 2 will only offer the alternatives if he is always paid according to his most profitable alternative. This is alternative y^B in Fig. 13. Hence, the payments must be fixed at

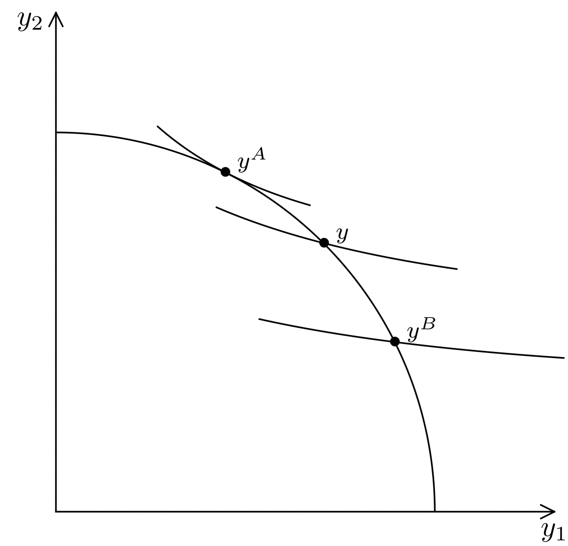

Fig. 12. Cost-neutral alternatives.

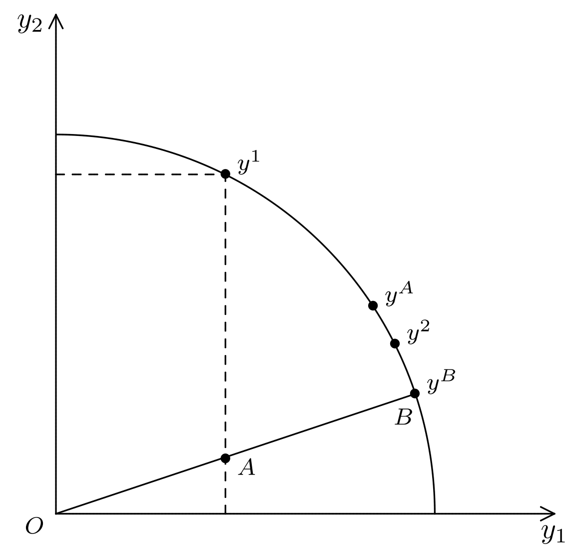

Fig. 13. Cost-neutral alternatives and relative performance evaluations.

$$t_2 = \frac{OB}{OA} x^1 \tag{26}$$

Hence, although the alternatives have equal costs to agent 2, he would have to be also equally compensated and thereby overpaid. The cost-neutral information is not revealed for free.

This is not to say that the idea cannot be useful in our case. If, for example, the principal signals his interest in y^2 as in our example and promises to pay agent 2 according to our yardstick plan for y^2, he could ask the agent to also propose a cost-neutral alternative that is less differentiated, such as y^A. If the agent knows this plan, he should be willing to provide information about it, and this will in turn reduce the payment to agent 1 using our yardstick scheme.

Of course, the principal can make similar proposals to agent 1 to further reduce the information rents. In the example he might propose y^C. This situation is illustrated in Fig. 14.

The total payment to the agents will then become

$$t_1 = \frac{OD}{OC} x^2 \tag{27}$$

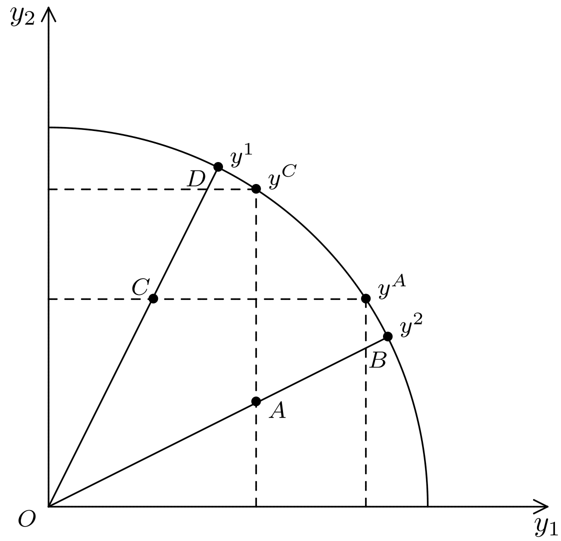

Fig. 14. Using cost-neutral alternatives to reduce information rents.

$$t_2 = \frac{OB}{OA} x^1 \tag{28}$$

which is less than previously (as in Fig. 5), since the benchmarks are more aligned. To sum up, if the agents have easy access to information about cost-neutral alternatives that are less differentiated, the principal can reduce the information rents even when the original proposals y^1 and y^2 are to be implemented.

6. Conclusion

In the context of regulating utilities that are natural monopolies serving different regions, consumers' preferences may differ between regions. This means that the utilities should ideally adapt their production plans to the specific preferences in their area. However, when the production plans differ across utilities, it complicates the cost comparison, i.e., the power of relative performance evaluation and benchmarking is reduced. Therefore, despite differences in consumer preferences, in some cases, it is optimal to let utilities produce the same set of services since the information rents associated with diversified service mixes outweigh the added value to consumers.

In this paper, we have considered a principal–agent model where the regulator, as the principal, negotiates with utilities (the agents) on their remuneration and service production. The regulator is assumed to maximize the value to consumers of the production plans that are implemented.

In the case of two utilities, two consumers, two services, no rationing, and with a cost function and preferences as specified in the base case, it is optimal for the regulator to forgo service differentiation to reduce information rent, i.e., it is optimal for the regulator to let the two utilities produce identical sets of services that fall between the preferred outcomes of the two consumers in a first-best world. With Leontief preferences, it is optimal to differentiate production plans, but not by much; production plans are still distorted compared to the first-best outcomes. However, increasing the magnitude of consumers' utility relative to the payment to the companies can make it more worthwhile to adjust to consumers' preferences. The number of utilities and service dimensions also have an impact on information rents and, hence, the optimal trade-off between service differentiation and information rents. A higher number of utilities would reduce information rents while a higher number of service dimensions would increase information rents. The functional form of the production function can also impact information rents.

The main policy-relevant insight of this paper is that benchmarking performance to limit information rents is less efficient when service providers are heterogenous. Regulators aiming at increasing the voice of consumers in regulatory processes will, therefore, have to address a trade-off between the usual efforts to minimize the information rents and the desire to maximize the adjustment to consumer preferences via service differentiation. Our findings emphasize that this trade-off may limit the impact of recent regulatory frameworks based on dialog and negotiations with utilities about which services to provide.

Future research could try to quantify exactly how sensitive the analytical results are to variations in the number of firms, service dimensions, consumer preferences, etc. In this way, we could better evaluate when dialog and negotiations with firms is most valuable.

Note also that while this paper has focused on scope, i.e., the question of whether the combination of different services should be allowed to vary according to consumer preferences, a related set of issues concerns scale. Future research could therefore also address the question of whether the regulator should allow, e.g., quality levels to vary across geographic areas, and how to balance a desire to exploit economies of scale in individual utilities and information rents in performance evaluations.

Another application of these considerations is in connection with merger cases. Mergers may lead to lower first-best costs, but information rents may increase as the disciplining power of relative performance evaluation is reduced when there are fewer utilities to compare. Regulators like the Norwegian regulator of electricity distribution operators, NVE, and the Dutch regulator of hospitals, NZa, are aware of this trade-off and have introduced different rules to balance them, cf. Bogetoft (2012). A careful analytical and numerical analysis of the role of mergers on information rents would, however, be relevant.

CRediT authorship contribution statement

Peter Bogetoft: Conceptualization, Methodology, Model formalizations, Formal analysis, Supervision, Writing. **Anita Eskesen:** Survey of international practices, Numerical calculations, Writing.

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