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Efficiency Measures in Regulated Industries: History, Outstanding Challenges and Emerging Solutions

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Chapter 20:

Efficiency measures in regulated industries:

History, outstanding challenges and emerging solutions

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1. Introduction

This chapter summarizes the evolution of the use of efficiency measures in efforts to improve the performance of key regulated public services. The review starts in the mid-1980s and concludes with the state of the art as being developed by academics in response to the practical difficulties to deal with resisting information asymmetries in the design and implementation of policies. In 2015, some of the main methodological improvements are indeed those that reduce the data requirements or the need to rely on assumption intensive methods, without having to give up on a sound economic performance analysis. The chapter shows that there is still some way in research to go to get these conceptual improvements to meet the policy needs and constraints in regulated industries. To contribute to this research, we suggest a more structural approach to efficiency measurement in the last section of the chapter.

The focus is on regulated activities, in particular infrastructure services, because they may be the policy area in which policymakers and academics saw some of the best opportunities to make the most of efficiency measures. But their policy use of efficiency is part of a much broader interest that started in the early 1980s. Many countries began, then, to favor market based approaches and a matching concern for efficiency. This switch in policy emphasis triggered a growing academic contribution to the debates on the scope for efficiency gains across a wide range of policy areas, including trade, labor and financial markets more notably.

It is in that context that efficiency and productivity measures became a goal as countries were adopting, or being forced to adopt, many of the reforms that eventually ended up characterizing the "Washington Consensus".[1] Increased competition as a way to increase efficiency became a central focus of the policy agenda of a majority of OECD countries and many developing economies interacting with the IMF and/or World Bank.

This is why the chapter starts with a few words on the major liberalization experience in the world in the last 30 years or so. Across policy areas, liberalization started to aim at cutting costs.[2] Many of the political speeches at the time also included an explicit promise to improve resources allocation, stimulate investments and ultimately work in the interest of contemporary and future consumers of a service or a good.

Infrastructure was somewhat of an outlier in that context. This is because its reforms went one step further. Some infrastructure reformers made the choice to set an explicit link between prices and efficiency as part of the design of regulation of the sector through the adoption of price caps. Price cap regulation was born as an alternative to traditional rate of return regulation for the telecoms sector to give an explicit incentive to service providers to cut costs.[3] What made it special was precisely that it required an efficiency measure to set, in advance, a maximum allowed growth path for the average price allowed for a specific product or service. This path was *explicitly* quantitative and this quantification was *explicitly* anchored into a specific measure of efficiency, which had to be the outcome of an *explicit* policy choice. No other liberalization had made this link that formal. In the process, efficiency was no longer only a goal, it was also becoming a tool.[4]

The instrument also pushed regulators towards an active and transparent performance monitoring role. Until then, the monitoring role of authorities was relatively passive since it

[1] The term "Washington Consensus was coined in 1990 by John Williamson to refer to a predictable set of specific recommendations made by the IMF, the World Bank and the US Treasury Department in negotiations with developing countries in crisis. Later, it ended up referring more generally to strongly market oriented reforms.

[2] There was a strong focus on cutting the cost of subsidies because fiscal discipline was often also on the policy agenda when sector reforms were taking place.

[3] In OECD countries, it is known as the brain child of S. Littlechild (1983) who eventually became the energy regulator, but economists in Chile argue that the specific mechanism has already been introduced in Chile prior to the 1983 Littlechild report. See for instance Galetovic (2008).

[4] Measuring efficiency change also aimed, initially at least, at ensuring fairness in its distribution between users and operators (and sometimes taxpayers when subsidies were part of the financing equation). An efficiency level of X guaranteed consumers (and/or taxpayers), a minimum level of average tariff reduction from costs savings and a fair return to the operator. Any efficiency gain higher than X would become a pure rent. Any gain lower than X implied a lower than expected profit and revealed that, either the operator was simply not very technically good at doing what it was supposed to do (adverse selection), or that it was not trying hard enough (moral hazard).

largely consisted in a validation of expenditure bills by the operators.[5] With the need to measure efficiency, regulators were expected to take a much more active role in measurement. The new role for regulators implied collecting data on costs and production at a level of detail that they had never had to collect until then. They also needed to engage in debates with the operators to assess the right methodology to assess costs, production or revenue functions in environments in which cost accounting rules were still quite partial and subject to relatively strong arbitrary cost allocation rules.[6]

Over the years, the use of the efficiency concepts has evolved though. The original price caps have also often evolved into hybrid regimes. These regimes now include a significant share of costs enjoying automatic pass-through rules, reducing the incentives operators face to improve their overall efficiency performance. These changes have also reduced the risks operators need to face and hence their expected returns on investment. In some countries such as the UK, the Netherlands, Norway or Sweden, the regulatory tool kit anchored in efficiency measures has also been diversified to include systematic benchmarking of performance (but this is discussed by Agrell and Bogetoft in another chapter).

Over time also, it has become clearer that the adoption of efficiency as a tool would not be evenly distributed across sectors and countries. It is much more common in energy and telecoms than in other sectors. It is also a lot more common in Anglo-Saxon, Northern European and Latin American countries than in other parts of the world. Moreover, the access to data by academics to allow independent assessments is still often limited, suggesting that there is scope for reform in the definition of the role and obligation of government in providing evidence on the performance of the firms they supervise or regulate.

There is, however, enough diversity in experiences and enough evidence on the evolution of the policy use of efficiency to identify successes, recurring concerns and to discuss possible solutions to these concerns. Academics have significantly improved their understanding of the policy challenges over the years. A lot of the current research aims at identifying ways to come up with better ways to generate policy oriented efficiency evaluations. The most relevant may be those emphasizing solutions in the context of seriously limited access to information, as this chapter shows.

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[5] This perverse effect of traditional forms of regulation is known as the Averch-Johnson effect and it translates into overinvestment in quantity and quality, which itself usually implied lower economic efficiency.
[6] See Campos et al (2003).

The rest of the chapter is organized as follows. Section 2 summarizes where the craving for liberalization comes from, as a ways of setting the stage to discuss how efficiency measurement has become so central in the performance assessment of key public services. Section 3 discusses how efficiency has become both a goal and a tool in some sectors. Section 4 offers a short survey of the many conceptual and empirical issues that the more technical literature has been arguing about in the last few years and that are relevant in the context of regulated industries. Section 5 makes the case for a switch to a structural ETC approach to the measurement of efficiency in policy areas as a solution to many of the issues identified. It focuses on concerns with information asymmetry and data availability and quality. Section 6 concludes.

2. Evolution of the measurement of efficiency effects of reforms.

The most talked about liberalization reforms in policy circles have tended to be those conducted in areas aiming at achieving macroeconomic transformations. The liberalization of international trade and capital flows were at the top of the neo-classical policy recipes built-in the Washington Consensus. Their main purpose was to induce major structural economic changes which would increase the overall efficiency of the economy as well as the efficiency of key public services. The expected efficiency changes had to be measured ex-ante to make the case for reform and ex-post to assess the extent to which the promises were achieved.

Most of these ex-ante assessments focused on assessments of cost savings as a proxy for efficiency, but there were many other ways in which the ex-ante assessment of potential efficiency gains came across in the literature and in the policy debates. The diversity of approaches to make the case ex ante is too broad to be discussed here. They ranged from detailed assessments of changes in total factor productivity during partial liberalization episodes in the context of specific case studies,[7] to computable general equilibrium models used to track the cross sectoral indirect effects in the 1980s.[8] There were also assessments of counterfactuals anchored sometimes in sophisticated accounting approaches.[9] Many of these assessments based the counterfactual on econometric studies, which were later discredited for suffering from, what we know now, significant technical limitations.[10]

[7] See for instance Krueger (1978, 1984).
[8] See for instance Dervis et al (1989).
[9] See for instance Galal et al (1994).
[10] See for instance Dollar (1992) or Edwards (1998).

The global message emerging during the 1980s and 1990s, in spite of the diversity of assessment methods, was that efficiency had improved or would improve with the changes. It had been largely coherent initially, but this only lasted for a while. Many of these results started to be questioned during the 2000s. The initial enthusiasm for the efficiency gains to be achieved was increasingly being seen as excessive, and new research was showing that the early reform experiences had not always been as efficient, nor as equitable, as expected for specific countries.[11] In an environment in which technical change was progressing quite fast and included an exceptionally fast global dissemination of knowledge, markets failed more often than initially anticipated, and efficiency-equity trade-offs were a lot more real than anticipated by the early research.

The failures reflected the fact that the initial models had not internalized the dynamics of optimization and many of the violations of the core efficiency (and equity) concerns that should have been addressed better. In retrospect, the specific measurement of efficiency and the use of the concept in policy circles had increasingly become ideological and less conceptually precise or rigorous. Picking the right sample of country or sector studies guaranteed the conclusion in favor of or against the reform. Many papers on the impact of privatization, for instance, picked the telecoms sector as a proxy for infrastructure.[12] Telecoms has benefited a lot from reforms aiming at increasing competition, but most importantly from technological change. This has not been the case for all sectors, in particular in developing countries for instance, where competition did not always deliver the efficiency gains on the scale expected. Focusing on telecoms was thus at least misleading to some extent.[13]

These observations reflect the importance of recognizing the consequences of an overly mechanistic and narrow use of efficiency concepts in policy debates. Ignoring uncertainty, data quality, data access, market specificities or more dynamic concerns, in particular the effects on investment, influenced the quality of the analysis. It also influenced and biased the conclusions on the efficiency payoffs of liberalization and structural reforms. It explained the difficulty of reconciling the factual evidence observed in the countries with some of the enthusiastic results that were widely disseminated in academic publications and quoted by some of the policy actors pushing for the reforms.

[11] See for instance Chisari et al (1999), Estache et al (2001) or Rodrik (1995, 2006).
[12] Megginson and Netter (2001) is one of the most widely papers quoted with this bias.
[13] See for instance Estache et al (2006).

For many observers then, it was quite rational to start questioning the methods used to assess the efficiency performance in complex contexts, including those suffering from major structural changes. Technically, the problem was not just a selection bias in data choices or market definition. The evolution of the literature shows that there were also selection biases in the choice of measurement techniques. In the early years, assessments relied on large panels of country data to conduct (sometimes only implicitly) counterfactuals (e.g. Dollar (1992) or Edwards (1998)). The results were attractive to the supporters of reforms, but were not as robust as claimed because of major technical flaws.

These flaws explain why many of the early studies were eventually invalidated.[14] Recently, more suitable experimental design, better data collection efforts and a stronger focus on the microeconomic evidence at the firms' and households' levels are refining the analysis.[15] In some cases, these methodological improvements have allowed the generation of more precise information on efficiency improvements, but the data and methodological challenges continue to be significant enough to justify additional research efforts.[16] The real issue however, may be that research has, in many ways distanced itself from policy concerns and become increasingly focused on narrow technical contributions.

Efficiency measurement in infrastructure has suffered from many of these general problems since the early days of high policy impacts in the 1990s. The research started with creative ways of generating counterfactuals.[17] It then moved on to much narrower concerns as it had done in trade, finance or labor research. In infrastructure the applied research focused on the generation of quantitative evidence (with a wide range of sophistication levels) on the efficiency performance of the regulated sectors and the unbundling of the efficiency into its various components.[18] In the process, the distance between conceptual and empirical research was growing because the research was not really recognizing that a main reason for this widening gap was the failure to account in research for the lack of interest of policy makers in adopting processes that would reduce information asymmetries. Academics and policy advisors continued to make significant technical contribution but did not really deal with the

[14] In trade, for instance, the technical debates became quite refined but with very strong policy implications. See for instance Rodriguez and Rodrik (2001), Alcalá and Ciccon (2004) or Rodrik (2006).

[15] See for instance De Loecker (2011) or Asker, Collard-Wexler and De Loecker (2014).

[16] Many of the problems stem from basic data constraints. For instance, productivity measures in this literature often rely on production functions in which firm level output is approximated by sales deflated by sector wide producer price indexes with predictable biases. This can bias efficiency effect assessments, as suggested by De Loecker (2011, 2014).

[17] e.g. Galal et al (1994) or Chisari et al (1999)

[18] It also included efforts to implement the conceptual vision defended by Schleifer (1985) to push for yardstick competition, as discussed by Agrell and Bogetoft in their chapter.

perverse incentives linked to the political rents allowed by information asymmetries in regulated industries. [19]

Strong methodological debates between schools of thoughts (i.e. parametric vs. non parametric) dominated many of the discussions in the main academic journals interested in efficiency measures, including the *Journal of Productivity Analysis* and the *Journal of Regulatory Economics and Utilities Policy*.[20] International organizations such as the World Bank also contributed to the disseminations of these applied techniques. [21] These allowed some of the academic research to trickle down to the practice of efficiency measures, as countries were internalizing many of the lessons of earlier mistakes or weaknesses.[22] The learning is still going on and countries at the frontier of regulatory practice, such as Australia, continue to mobilize significant efforts to raise awareness of the importance of these measures among less specialized audiences. [23] However the challenge of ensuring the dissemination of robust research in the policy arena, and its adoption in policy design, is not a minor one.

3. From efficiency as a goal to efficiency as a tool: learning from infrastructure

Making efficiency a general goal of policy was already quite a change in philosophy for many policymakers. Making it happen in practice proved to be quite challenging but do-able. In the context of infrastructure policy, it was implemented in three ways. The first was a change in the market structure to unbundle and give opportunities to potentially competitive segments to achieve their potential. The second was the introduction of competition for the market, when the scope for competition in the market was limited. This is where developments in auction theory during the same period made a big difference. The third was to think of ways of designing regulation of the residual non-competitive segments of the sector to achieve desirable efficiency improvements.

[19] See Campos et al (2003) for an illustration in the context of the Argentinean railways.

[20] These debates are regularly synthesized in textbooks on efficiency measurements by some of the main academic contributors to the field (e.g. Coelli et al (2003) and Fried et al (2008)). More recently, Grifell-Tatje and Lovell (2015) have been arguing for a third way capable of making the most of accounting data.

[21] e.g. Coelli et al. (2003)

[22] The way the Dutch regulators organized the measurement of efficiency when it first focuses on its measurement is a good example. It relied on some of the top British specialists in the field that also had regulatory experience to ensure the most effective transfer of knowledge and immediate internalization of the British experience.

[23] E.g. Coelli and Lawrence (2006)

Some combination of these changes characterized the transformation of sectors such as energy, telecom or transport. As in cases mentioned earlier, in infrastructure, the efficiency goals initially largely meant assessments of the scope for costs savings conceptually. In practice, the quantification of these goals often did however not go much further than the focus on labor productivity or other types of partial indicators focusing on different costs drivers. The improvements to be achieved from sector restructuring to increase competition were based on comparisons with best practice benchmark indicators, typically used by engineers and financial analysts specializing in the sector.[24]

Frustration with the incoherencies associated with partial indicators led to a more precise concern for the measurement of efficiency.[25] This concern progressively became central to the research and the practice of regulation of public services. It was also slowly turning the measurement of efficiency into a tool for reform in itself, with the adoption of regulatory regimes relying on some explicit efficiency measure. This happened because academics and policy advisors had managed to mainstream the idea that measuring efficiency could be useful as a full component of the restructuring of the sectors. Restructuring was not only about pushing for competition, it also had to be about coming up with ways to track the effectiveness of reforms, and using the limited information available to regulators to provide the incentive to the firms to continue to try hard to work in the interest of users as much as in their own interest.

This is now well understood in policy circles (even if not that much in political circles). But it is a relatively recent recognition. Less than 30 years ago, the information asymmetry was seen as a fact of life. Besides detailed audits, little could be done to deal with it. Old fashioned regulation and competition policy were designed to avoid abuses in markets with imperfect competition. Efficiency measures were not really explicitly built in in the regulatory tools. Incentives to cut costs were the outcome of negotiation between regulators and the firms, instead of the implementation of a regulatory regime anchored explicitly and mainly in efficiency concerns.

The adoption of regulation designed to allow an explicit concern for efficiency in environments in which agents have more information than their principals was, in fact, the result of developments in economic theory that made it to the policy arena. The very basic

[24] A simple look at the World Bank reports of the time will validate this assertion.
[25] See Coelli et al (2003) for a discussion of the biases linked to partial indicators in the context of infrastructure.

insights were provided by Baron and Myerson (1982). [26].They offered the first model of a single product monopolist in a static setting, suggesting that efficiency gains could be achieved without having access to the full set of information on the firms that a regulator may need to monitor. They came up with a Bayesian regulation scheme in a setting in which the regulators did not know the costs of the firm they were supervising. Their model characterized the information gap as the need for the regulator to rely on subjective probabilities on the unobservable technical efficiency potential of the service providers.

Their adverse selection model was quickly refined by Sappington (1983) to account for the possibility of ex-post monitoring of costs for a multiproduct monopoly. It was further improved by Laffont and Tirole (1986) to account for the possibility of moral hazard as a driver of inefficiency. Lewis and Sappington (1988) then eventually showed that these models could also work in cases in which the source of information asymmetry was the demand side. During the following years, these theories continued to improve, by integrating the concerns for dynamics and quality for instance (e.g. the overview in Laffont and Tirole (1993) and more recently in Armstrong and Sappington (2007)).

These new theoretical approaches to the optimal design of regulation pointed to five relevant facts in the context of this chapter:

i. Information asymmetry are a fact of life, but should not be seen as an impediment to efforts to achieve efficiency in either a static or dynamic sense (since the games between regulators and firms could be repeated).
ii. Making an effort to measure efficiency ex-post makes regulation more effective in stimulating performance, since the specific regulatory mechanism is possible. However, its effectiveness depends on the size of the information asymmetry between the regulators and the firm.
iii. The subjectivity of the regulator could influence the level of efficiency that could be aimed at (since probabilities are subjective in these settings).
iv. The decision to push for efficiency in an information asymmetry world implies that regulators have to promise the firms the right to keep a share of efficiency gains larger than they would have enjoyed in a world of full information. This can be politically difficult to sell, which may explain why some regulators prefer to be protected by the veil of ignorance.

[26] E.g. Dobbs (2004)

v. If regulators aim at maximizing efficiency and are willing to be rational about the management of the information asymmetry, firms have to be given some flexibility to achieve their efficiency goals.

The main gap in these theories was a specific guidance to turn these lessons into an explicit mechanism able to rely on data relatively easily available from firms. This gap was closed with the price-cap mechanism suggested by a 1983 report on suggestions made by S. Littlechild to change telecoms regulation in the UK. His suggestion was to link an allowed price change to (i) changes in a price index exogenous to the regulated firm, but also to (ii) an efficiency (discount) factor set by the regulator.

It was a very pragmatic interpretation of the lessons from theory. Many other equivalent mechanisms, demanding a specific measurement of efficiency have since then been published.[27] But this creativity has not been able to meet all needs, since not all countries have switched to regulation anchored in efficiency measures. Even so, Table 1 shows that there is a broad range of case studies to pick from across the world and across sectors..[28]

Table 1: Examples around the world of sectors in which incentive based regulation is anchored in a measurement of efficiency through a price cap or some alternative form of benchmarking

	Electricity	Gas	Telecoms	Water and Sanitation	Airports	Ports	Rail
Argentina	x	x	x			x	
Australia	x	x	x	x	x (till 2002)	x (till 2009)	
Austria	x	x			x		
Brazil	x	x	x	x		x	
Chile	x	x	x	x		x	
Czech Rep.	x	x					
Germany	x	x		x	x		
Hungary	x	x	x		x		
India	x					x	
Ireland	x	x	x		x	x	
Mali	x		x	x			
Mexico	x	x	x		x	x	
Netherlands	x						
Portugal	x	x					
Senegal	x		x				
Spain	x	x	x				

[27] An earlier paper by Loeb and Magat (1979) had already addressed the importance of information asymmetry in the context of regulation, but it did not generate the awareness of the importance of efficiency measurement hinted at by Baron-Myerson and its follow ups.

[28] There are many good reasons why in some countries it is quite rational not to overemphasize efficiency, in particular when institutional capacities and concerns for risks are limited. See for instance Estache and Wren-Lewis (2009) for a detailed discussion in the context of developing countries.

Sweden	x				x		
UK	x	x	x	x	x	x	x

Source: Authors' compilation from multiple sources.

Littlechild's idea became itself the focus of a large number of theoretical and empirical studies considering its potential and limitations in the context of specific sectors (e.g. the overviews in Joskow (2008, 2011) for electricity and Sappington and Weisman (2010) for the telecom sector). Most of this initial research focused on static views of efficiency and relatively mechanistic uses of these measures, until Cowan (2002) argued that perverse effects on dynamic efficiency, in particular in a context of uncertainty, was a serious risk. The concern was confirmed by a large number of researchers and eventually led to the suggestion of modeling price caps through option pricing models. This suggestion remained an academic one, but the main implicit message (i.e. that the static approach was biasing the interpretation of the efficiency measurement and misleading the evaluation of the policy challenges) trickled down to policy discussions and further empirical research.

This empirical follow up research raised a number of measurement issues as well. Besides the obvious concerns with access to data and the poor quality of the data available in regulated industries, the most noted issue in policy discussions was linked to the importance of investment and other adjustment factors with intertemporal dimensions. There was a need to distinguish between operational and capital expenditures more systematically when assessing efficiency. If this distinction is not done in static models and efficiency is based on total costs, any increase in capital expenditures could be interpreted as an inefficiency and hence overestimate the efficiency factor in price regulation. [29].

The concern has been documented for a sample of EU energy utilities from 1997 to 2007, by Cambini and Rondi (2010) for example. They show that the investment behavior of incentive-regulated firms can be negatively related to the level of the efficiency goal set by the regulatory authority if this goal is not defined precisely enough. Transitory inefficiency may be confused for operational efficiency. The impact of the confusion depends on how regulation is implemented in practice, as argued by Vogelsang (2010). Unfortunately, it is still common, even if it has generated a lot of academic research.[30] From a very pragmatic viewpoint, the implicit conclusion is that it is really necessary for any efficiency analyst to pay more attention to the specific characteristics of the markets being analyzed.

[29] Joskow (2008)

[30] See for instance Fare and Grosskopf (1997) and Fallah-Fini et al (2013).

In sum, within less than 30 years, the process that had transformed efficiency into both a central goal of policy and a key instrument in the effort to achieve that goal has also been an opportunity to reveal a wide range of outstanding issues. These issues concern both the way efficiency is being measured and the way these measures are being interpreted and used in policy circles. Internalizing these lessons implies a greater responsibility for those that construct and advocate the efficiency indices than sometimes recognized. It may also require a more structured approach, which deals with many of the issues raised above in a transparent and systematic way. This approach must also be able to deal with the major empirical challenges analysts often face. This is the focus of the next section.

4. Typical empirical challenges and the debates on how to deal with them

Table 2 summarizes the research on the most recurring types of empirical issues identified by practitioners. It shows that, over 30 years after the beginning of the discussions on how to measure efficiency for regulatory decisions, the modeling of production processes continues to be an area of contemporary interest in both the operations research and economic literature.[31]

Table 2 shows the main empirical issues that resulted in big divides between the regression-based economics literature (i.e. the parametric school of thoughts) and the deterministic optimization-based operation research (OR) literature (the non-parametric school of thoughts).It shows that the main sources of the divide are also some of the main empirical concerns that need to be tackled by any analyst in the field:

(i) The common necessity to rely on noisy data.
(ii) The difficulty of linking input choices to unobserved technological variations.
(iii) The necessity of dealing with the multiproduct nature of firms in a way that recognizes the relation of the different production processes, each with their own scale and scope economies.
(iv) The need to rely on strong assumptions on prices in environments in which prices are more often negotiated confidentially rather than set in the market.
(v) The need to rely on functional form assumptions simply because the real production processes are kept confidential.

[31] In Cherchye et al (2015), we provide a fairly complete list of challenges of the empirical analyst with a non-exhaustive listing of references.

Each source of divide leads to a preferred ranking between econometric and OR approaches. Noisy data is quite common in environments in which cost accounting is partially subjective, which is a recurrent issue in regulated industries. The problem is standardly assumed away in the nonparametric OR literature but it is allowed for, by default, in any regression-based analysis..[32] An additional significant difference between the two main approaches is in the concern for endogeneity. The OR literature has also been quite silent in recent decades about this issue occurring if input choices of firms are based on an unobserved productivity component. The problem can however be dealt with in various ways. Olley and Pakes (1996), Levinsohn and Petrin (2003), Ackerberg et al (2006) and Wooldridge (2009) have all developed (semi-) parametric (proxy variable) approaches.

<table>
<tr><th colspan="7">Table 2: How does the literature on efficiency measures in industries with major informational problems and gaps</th></tr>
<tr><th></th><th>Empirical issues</th><th>Noisy Data</th><th>Input choice with unobserved technological variation</th><th>Multiproduct firms</th><th>Unobserved prices</th><th>Unknown functional forms</th></tr>
<tr><td rowspan="2">Established wisdom</td><td>Economic literature</td><td colspan="2">(semi-) parametric regression framework:
Olley and Pakes (1996), Levinsohn and Petrin (2003) Ackerberg et al (2006) and Wooldridge (2009)</td><td></td><td colspan="2">Non-parametric framework:
Afriat (1972), Hanoch and Rothschild (1972), Diewert and Parkan (1983) and Varian (1984)</td></tr>
<tr><td>Operations Research</td><td colspan="2"></td><td colspan="3">Data Envelopment Analysis:
Charnes, Cooper and Rhodes (1978)</td></tr>
<tr><td rowspan="3">Recent challenges to wisdom</td><td rowspan="2">Economic literature</td><td colspan="4">Semi-parametric regression framework for multi-product firms:
Foster et al (2008), Bernard, Redding and Schott (2010, 2011) and De Loecker (2011)</td><td></td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="3" rowspan="2">Non-parametric multi-output framework with output-specific technology sets:
Cherchye et al (2008) and Cherchye et al (2013, 2014)</td></tr>
<tr><td>Operations Research</td></tr>
<tr><td colspan="7">This review is partial and does not deal with a lot of what can be done with stochastic frontier analysis (SFA) when data constraints are not a problem. See Fried et al (2008) and Coelli et al (2005) for overviews in those contexts.</td></tr>
</table>

The third divide is about how to deal with the fact that multi-product firms are the rule rather than the exception.[33] On this front, the OR literature has long had some advantage. It standardly allows for multi-output production settings and can cope with unobserved prices by the use of shadow prices. Technically, every linear programming problem can be expressed in a primal problem and a dual problem. Specifically, if (technical) efficiency is

[32] Note that there are errors-in-variables techniques available to allow for measurement error in a deterministic OR framework See for instance Varian (1985) and Kuosmanen et al (2007) for seminal contributions and Daraio and Simar (2007) for an overview.
[33] See Panzar and Willig (1981) .

anchored into an identification of the underlying optimization behavior of the producers, it can be considered as an upper bound approximation of the real (economic) efficiency (see also Section 5 for more details). For example, the linear program for technical efficiency measurement in the input direction for a setting with convex input sets will turn out to be dual to a linear program that computes cost efficiency. In economic terms, the technical efficiency estimates tell us the extent to which firms are cost minimizing when using shadow prices for the inputs.

The econometric techniques can also deal with multiple outputs and multiple inputs.[34] It is typically done through distance function formulations. In spite of its attractiveness, the approach tends to suffer from endogeneity problems for many types of activities. To avoid the problem, some assumptions may be needed, which can be quite strong for certain markets. For the input distance function, the analyst needs to assume that outputs are exogenously given. For regulated industries in which service obligations are the norm, the assumption is credible. It is not when outputs have to be considered to be endogenous. For output distance functions, there is an equivalent assumption with respect to the exogeneity of inputs, which can be a problem, also in regulated industries. Note that, despite these problems, the technique is quite widely used in regulated industries such as railways and electricity, which suggests that many analysts do not believe that the endogeneity problem is always a major issue.

A more subtle aspect of the modeling of the nature of the production activity is the issue of output-specific technologies and input assignment. Cherchye et al (2008) and Cherchye et al (2013, 2014) extended the framework of Afriat (1972), Hanoch and Rothschild (1972), Diewert and Parkan (1983) and Varian (1984) by proposing a nonparametric multi-output framework with output-specific technology sets. An interesting feature of this multi-output methodology is that it can be extended to a setting of multi-product firms, which may differ in product mix. This flexibility is an added asset of OR in many settings.

The fourth source of disagreement between the two main schools of thoughts is the challenge imposed by unobserved prices. It is a serious issue even if the disagreement between the OR and econometrics analysts is becoming less important in practice. Until very recently, regression-based approaches neglected the particularities of multi-output production, and used industry-wide deflators to overcome the issue of absence of firm-product-level prices.

[34] See for instance Coelli and Perelman (1999) for one of the earliest applications in a regulated industry.

Neglecting price heterogeneity across products and across firms can imply systematically biased productivity estimation, and this has been recognized by a wider range of authors.[35] Some of the existing solutions are that products are aggregated to a single measure of firm production by e.g. the use of a firm-level price index or a transformation function.[36] Recently, De Loecker (2011) has shown that the problem could also be addressed by including information on demand shifters into the production model, and Bernard et al (2010, 2011) endogenized the selection of the output portfolio.

The last source of divide is the approach to the functional form specifications. It is an important one, since it can bias inference in an unknown direction. Until very recently, the regression-based efficiency literature largely ignored the potential functional misspecification bias and heavily relied on an a priori imposed increasingly complex parametric structure. The nonparametric linear programming methodology, which is popular in the recent operations research literature, can define efficiency conditions on e.g. prices, technological change and productivity from observed production behavior without imposing parametric structure. The most popular operationalization of this approach is Data Envelopment Analysis (DEA).[37] One of the main advantages of the nonparametric approach is that it requires no a priori specification of the functional relationship between the production factors, environment and firm production, hence reducing the possibility of a functional misspecification bias.

Overall, what this discussion shows is that the economics literature emphasizes endogenizing firm choices in a noisy setting by building a (semi-)parametric framework, while the OR literature focuses on the potential functional misspecification bias, unobserved prices and the multi-output structure of production. In a nutshell, for decades, the two strands of literatures have been drifting apart. Yet there are also striking similarities in the way the two approaches deal with empirical difficulties. There is, notably, a tendency of dealing with the main empirical challenges simultaneously in both strands of the literature. Therefore the empirical analyst can cherry-pick an empirical approach according to the empirical setting rather than to follow a dogmatic belief in a particular strand of literature.

In practice, it means that it is essential to be pragmatic rather than dogmatic in the choice of the approach, without forgetting the importance of the economics underlying the efficiency diagnostic. While for a vast majority of situations, a regression-based framework is most

[35] See for instance Klette and Griliches (1996) and Foster et al (2008).

[36] Diewert (1973) introduced the transformation function for two goods and Dhyne et al (2014) extended this to any number of goods.

[37] See Charnes, Cooper and Rhodes (1978)

appropriate, in the next section, we argue that for regulated activities facing significant information gaps and data gaps, a constrained optimization (e.g. linear programming) framework is often more promising. The inclusion of a concern for the optimizing behavior of the actors in the efficiency diagnostic is what makes it special and less anchored into an engineering/mechanical vision of the performance diagnostic. With the benefit of significant research progress in recent years, this approach would be able to deliver a more reliable approximation of efficiency at the firm level, especially if use is made of recent advances in the literature to tackle empirical difficulties.

5. Towards a structural view of efficiency measurement in regulated industries

The ongoing debates on the proper policy use of efficiency measures and on the proper measurement itself reveal two more complex and growing problems. The first is a lack of systematism in the approaches taken by analysts to generate efficiency measures that can anchor policy decisions. As a result, there is a lot of subjectivity in the way the efficiency analysis is anchored, and this can lead to approaches that can range from careful assessments of the behavioral and optimization options or preferences of the operators, to fairly mechanical approaches aiming mostly at generating specific efficiency measures that can be used to launch a regulatory dialogue. The growing bias towards this more mechanical approach is the second problem. It reflects a certain banalization of the measurement process.

These problems suggest that there is often a missing required step in the process followed to generate an efficiency measure capable of informing the policy analysis in an economic diagnostic of the performance of a firm. This step has to capture the extent to which production or management decisions are influenced by (implicit or explicit) optimization behaviors with predictable constraints and biases.

From an economic policy or regulatory policy perspective, it seems to us to be essential to start the efficiency diagnostic with an understanding of the market being assessed, of the goals of the actors involved in the market, and of the implied optimizing behaviors. It only makes sense to focus on the actual quantification process, when this first essential step is done. The omission of this step may be one of the most underrated issues in the practice of efficiency measurement.

Our sense is that a reasonable way of minimizing the risks of jumping too fast into the empirics is to rely on a three step process that ensures that the analysts has covered all the key dimensions:

(i) Spell out the **E**conomic objectives that motivate the assessment.
(ii) Identify the production **T**echnology used to optimize the economic objectives.
(iii) Implement the empirical strategy, starting with a diagnostic of the range of **C**hallenges linked to the multiple dimensions of information asymmetry.

We label the approach ETC for short to reflect the fact that the focus is first on the economics (**E**), next on the technology (**T**) and then only on the implementation challenges (**C**).[38] The rest of the section explains how to work through each one of these three steps.

Step 1: Spelling out the economic objectives. Any efficiency analysis relevant from an economic perspective should ideally start from an explicit identification of the economic objective and market situation of the actor under evaluation. This allows a definition of efficiency as a measure of the deviation between observed behaviour and behaviour consistent with optimizing the economic objective. The efficiency measure then enjoys a clear economic meaning, rather than a more mechanical engineering interpretation. It anchors the policy issues in an explicit recognition that any inefficiency index is a measure of the deviation from optimizing the objective chosen or assigned to the actor under assessment (e.g. firm, regulator, society). Ignoring this underlying optimization process leaves the efficiency measure, at best, with a partial interpretation of the performance and, at worst, without a credible economic interpretation. In both cases, it can result in biased and misleading policy conclusions.

Consider technical efficiency, which measures the production performance of a firm. This type of efficiency is the most common focus of models used in regulatory policy and public sector performance assessments. These models aim at assessing whether or not the evaluated production unit is on the technically efficient frontier of some empirical approximation of the production possibility set (i.e. the set of technologically feasible input-output combinations). The main issue with the common use of the technique is that the construction of this possibility set is conventionally motivated from an engineering perspective. This perspective relies on often strong assumptions on dimensions such as returns-to-scale or the marginal rates of input substitution/output transformation. Yet production (i.e. the transformation of

[38] Cherchye et al (2015) provide a full discussion of our approach.

costly production inputs in valuable output (both products and services)) makes economic sense only if the production process is in line with pursuing the economic objective of the firm.

In the private sector, the most frequently maintained position is that producers operate in a fully competitive market and pursue profit maximization. In the public sector, however, cost minimization for given output might often seem a more reasonable assumption, e.g. when the producer is a price taker in input markets but operates in regulated output markets (as is often the case for public agencies). In other instances, a similar argument may motivate revenue maximization as the appropriate firm objective.[39]

It is worth stressing that specifying the specific economic objective and integrating the market constraints (e.g. price taker or setter, specified price caps or objectives,…) has an impact on the efficiency assessment. If this is not appropriately defined in the first step, then the next steps of the ETC-stepwise framework are of little use, as any following efficiency index, which captures deviations of the optimal behavior, will be without economic meaning and hence without much value for policy making. However, carefully selecting the appropriate economic environment is not always so trivial and thus requires some discussion. The following is a summary of the most important ingredients.

First, the analyst needs to distinguish between short-term and long-term optimization. This is important as some inputs are fixed in the short term and variable at the medium or long run. Moreover, in the medium or long term, the usually unknown negative or positive spillovers between sales, loyalty and various production risks may affect the production results.

Second, the economic objective can vary over time and over products. While revenue maximization can be a short term objective to e.g. control or increase the market share of an entering firm or a new product in a highly competitive market with scale economies, it is usually not the true long-term economic objective.

Third, the economic objective can be impacted by the economic environment in which the firm operates. Price caps and specific objectives set out by the regulator, or more generally the policy maker, influences the optimization decisions of the firms.

[39] Note that cost minimization and revenue maximization are required for profit maximization. However, profit maximization is in general a more stringent requirement then cost or revenue maximization: it may well be that a firm is cost minimizing and/or revenue maximizing but not profit maximizing. In that sense, cost minimization and revenue maximization may be seen as natural "*minimal*" efficiency conditions.

Last, as the firm can have a divisional structure (i.e. a horizontal, vertical, regional or mixed divisional structure), the objective can be introduced from a cooperative or non-cooperative perspective. The 'cooperative' perspective assumes that the separate divisions cooperate in order to reach the economic objective of the firm, while in the non-cooperative perspective individual divisions pursue their own economic objective. Clearly, such a set-up does not automatically imply cooperation between the different divisions. (Cherchye et al. , 2014)

Step 2: Identify the production technology used to optimally achieve the economic objective in the given economic context and introduce inefficiency as a deviation from optimal conduct. Given the economic objective and environment identified in step 1 and the definition of economic efficiency as the spread between observed and optimal behavior, the analyst needs to define the production technology used to optimize the economic objective, regardless of the availability of data. Firms strive in a given environment to optimize the economic objective by transforming inputs, which are costly, in outputs which have a (non-)market value, and choosing the optimal pricing strategy. Defining the technological information consists thus of:

a. Identifying the inputs, outputs and environmental variables and their relation to each other.
b. Identifying the input and output prices.
c. Defining what is controllable (endogenous) and non-controllable (exogenous).
d. Introducing efficiency as a deviation from the optimal conduct identified in Step 1.

The first three actions are relatively well-known and common practice, the last one is less common and yet what we believe an essential part of the overall process. The first two actions are taken usually assuming no information asymmetry on key observables. Full information on the production technology implies that we know which inputs are used for the production of each output and which environmental variables affect the linkages between the inputs and outputs. We also know all the relevant prices and that these prices affect how the firm demands inputs and supplies outputs in the input-specific and output-specific markets to optimize the economic objective. There is no need to assume the markets the firms are confronted with, are homogeneous over the production variables. As a result, prices are best defined at the input-output-environment level.

The modelling of the production can be quite detailed and specific. The analyst can distinguish between joint (or public) inputs, sub-joint inputs and output-specific inputs. Joint inputs benefit the production of all outputs and thus imply non-rival and non-exclusive use of the inputs within the firm. Sub-joint inputs also figure as joint inputs, but only for a subset of outputs. Output-specific inputs can be allocated to the production of particular outputs (e.g. by the use of an assignment factor which represents the fraction of the input that is used to produce the particular output; see Cherchye et al (2013)). As such, input-specific, output-specific and as well environment-specific technology sets can be constructed. If a separate production technology for each output (input) is considered, interdependencies between the different technologies are accounted for through jointly used (produced) inputs (outputs). Note at this point that the functional relationship between inputs, outputs and the environment is still unknown at this stage of an analysis. The potential need for specifying this relationship is part of step 3 of the ETC process.

Once the basic dimensions of the production process have been identified, the analyst has to identify the extent to which the firm can have discretionary power in the level of production variables, the selection of production variables and level of prices. Determining what is considered to be endogenous in the pursuit of optimizing the objective is key to understanding firm behavior. First, a meaningful technology defines which inputs, outputs and environmental variables are outside the discretion of the firm and thus exogenous to the maximization of the economic objective. Second, besides the level of production variables, the firm can influence the selection of inputs (e.g. using new innovations), output portfolio (e.g. upgrading or downgrading the portfolio depending on the output market) and operating environment (e.g. firm location, off-shoring, export choices, global sourcing). As such, the technology clarifies whether selection of production variables is endogenous to the maximization of the economic objective. Third, even if the prices are unknown, a meaningful definition of the technology requires a clear definition of which prices are endogenous to maximizing the economic objective. As prices are the result of the confrontation between supply and demand, it is in this step that information on input and output market structures should be included.

With the optimal and actual information requirements clearly identified, the analyst can now focus on the distance between the firm's performance in terms of the specified firm objective to the optimally feasible performance as a measure of the so-called economic efficiency, which includes cost efficiency, revenue efficiency and profit efficiency. Cost efficiency is the distance between observed costs and minimal costs (for a level of output) and revenue efficiency is the distance between observed revenues and maximum revenue (given inputs).

Analogously, profit efficiency is the distance between observed profit and maximum profit. While it is natural to consider deviations from optimal conduct solely in the negative direction, this framework is general in the sense we do not exclude deviations in the positive direction (e.g. caused by exogenous productivity shocks) that imply superefficient conduct.

As a test of the relevance of the efforts conducted up to now, the analyst can check if any appropriately defined technical measure of efficiency has a (dual) interpretation in terms of economic efficiency. If not, the analysis is false and without value for policy makers. Stated differently, a measured technical efficiency that does not approximate the distance between observed conduct and the conduct that optimizes the economic objective is of no use for policy making.

Step 3: Tackle the empirical challenges, which the analyst is confronted with, internalizing the many lessons from the limitations of older approaches. With the benefit of the theoretical approximation of the true unknown production process identified in Stage 2, the analyst can now start working on its empirical approximation. In many cases, the reliability and quality of the empirical approximation heavily relies on the chosen theoretical structure. But, as discussed in the previous section, it also depends on more down to earth sources of concerns.

For regulated sectors, the natural way of dealing with the unknown functional form, unobserved or imperfect price data and the many cases with significant data unavailability in panel format needed to be able to control for input choice dependency on efficiency, makes the OR framework quite attractive. In this framework, as production efficiency is anchored in production (input and output) data, the regulator avoids having to deal with the concerns for confidential costs data and avoids having to rely on a functional representation of the production technology (a recurring source of conflict between regulators and operators during tariff setting discussions, which often ends with the operators enjoying the benefit of the doubt). Regulated firms tend to be reluctant to provide detailed cost data, which often depend on negotiated agreements with their suppliers. Moreover, joint costs allocated to specific activities are usually based on subjective cost allocation rules, which distort any assessment of performance. In this context, it seems clear that relying on production data is attractive. Even more so, when the ETC framework can be used to give an economic meaning to technical efficiency in terms of deviation from optimizing behavior.

Furthermore, the approach can also be easily adapted to deal with a growing range of policy concerns relevant to regulated environments, such as services obligations, congestion or bad outputs (environmental concerns). These concerns can be fitted in, since a link between the economics and the technology choices are relatively easy to establish and to build-in the empirical tool. Service obligations simply reflect the fact that besides minimizing the input quantities, a regulator may wish to pursue specific output targets (e.g. increases of good outputs or reductions of bad outputs). This can be done by modifying the efficiency measures to include targets without involving specific engineering assumptions on the reference technology. Congestion problems are dealt with also by including them in the definition of the technology. This ensures that they are internalized by our definition of efficiency as the distance between the observed behavior and the optimum. Finally, a vast literature - referenced in Cherchye, De Rock and Walheer (2014) - deals with the issue of including undesirable outputs into nonparametric efficiency analysis, however without reaching consensus. While existing approaches either imply additional non-verifiable production axioms, transformations that may significantly alter efficiency results or extra modelling choices, Cherchye, De Rock and Walheer (2014) advocate a characterization of bad outputs in terms of their own production technologies (while allowing for interdependencies between bad and good outputs), by suitably applying the ETC approach spelled out above.

6. Concluding comments

For over 30 years now, theoretical and empirical academic research has been trying to improve the way efficiency is measured and how it can be used in the design of regulation in environments in which information asymmetries and data gaps and quality are serious issues. This survey shows that the efforts have been quite successful in many ways. How precisely analysts can deal with real life data and informational constraints in their efforts to measure efficiency is quite different today from what it was when regulators started measuring it. Efficiency analysis is, indeed, significantly better now and it can lead to significantly more robust results. This is the good news, but there are also some remaining caveats to keep in mind at the end of this review of the match between the theory and practice of efficiency measurement.

First, there is still a major informational problem. The creativity of theorists in coming up with solutions to make the most of the use of efficiency in policy decisions in a world of sustained informational asymmetries has helped. Unfortunately, it has not yet managed to offset the data and other informational challenges as much as needed to obtain fair assessments that minimize the scope of strategic use of methodological biases in policy debates (e.g. between regulators and regulated firms).

Related to this, there is an informational problem because key policymakers are not doing enough to close a gap which is known to generate rents. The reasons for this lack of effort are multiple and are better dealt with in discussions of regulatory capture, collusion or corruption.[40] But the slow progress in closing the gaps, and in using some of the latest techniques available to reduce the impact of these gaps in optimal policy research, points to a clear need to factor-in these perverse incentives in the design of regulation. This includes the concern for improvements in efficiency and the fair sharing of gains between producers, users and taxpayers.

Thirdly, the reaction to the informational gaps has too often been to rely on a relatively mechanical approach to the assessment of efficiency. Problems are assumed away rather than addressed in the policy use of efficiency measurement techniques. Indeed, axioms and audacious assumptions on the irrelevance of key informational issues are quite common and not necessarily carefully tested. Bootstrapping techniques help but do not sort out the problem. In particular, they do not really deal with the fact that an analyst can choose to ignore the nature of the optimizing behavior of the agents. Yet this is what makes the difference between an engineering and an economic perspective on efficiency. Without an explicit recognition of the behavior driving the optimization process, it seems hard to design policies that factor-in the behavioral distortions that influence performance. This is where the discipline imposed by the ETC approach we suggest may help, since it anchors the definition of efficiency into a structural assessment and specification of the optimal behavior.

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[40] For a recent survey, see various chapters in Rose-Ackerman and Soreide (2012)

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