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Conditional Yardstick Competition in Energy Regulation

Timo Kuosmanen* and Andrew L. Johnson**

Yardstick competition is a regulation regime that forces local monopolies to compete against a variable cost or total cost benchmark. The variable cost benchmark ignores the fixed capital, creating a strong incentive to over-invest, whereas the total cost benchmark assumes all costs to be variable, ignoring the investment risk. We propose theoretical, methodological, and operational advances to increase applicability of yardstick competition in energy regulation. In the proposed conditional yardstick regime capital is treated as a fixed input, and the local monopolies compete against the variable cost conditional on the fixed input. We develop a benchmarking method that can handle multiple outputs, heterogeneity, and shape constraints to ensure incentive compatibility. We discuss the real-world application of the proposed regime to the Finnish electricity distribution firms in 2016-2023. We argue that smarter regulation of network industries can contribute to lower risk premiums and help to achieve win-win solutions both in terms of reliability and affordability.

Keywords: Electricity distribution, Heterogeneity, Incentive regulation

JEL Codes: D24, L51, L94, Q48

1. INTRODUCTION

Market competition in the energy generation and the retail trade of electricity critically depends on electricity transmission and distribution. Free entry and exit to the retail electricity market requires that the transmission and distribution firms are impartial agents that do not favor one producer over another (e.g., Burger et al., 2019). Impartiality is particularly important for the market access of decentralized renewable energy such as wind and photovoltaics. The retail market of electricity cannot converge to a competitive equilibrium if the supply chain of electricity has significant capacity constraints or reliability issues.

Electricity transmission and distribution are prime examples of network industries with a large fixed cost and a natural monopoly as the most cost efficient industry structure.[1] To alleviate the abuse of monopoly power, the government regulators have traditionally restricted the tariffs by applying price controls such as the price cap, the revenue cap, or the rate of return regulation (e.g., Kahn, 1971; Armstrong et al., 1994; Newbery, 1999; Jamison, 2007). To provide further incentives to provide acceptable level of service as cost efficiently as possible, many regulators around the world combine price controls with best-practice benchmarking (e.g., Jamasb and Pollitt, 2000; Pollitt, 2005; Haney and Pollitt, 2009; Agrell and Bogetoft, 2010; Bogetoft and Otto, 2011). The economic rationale of benchmarking builds upon Shleifer's (1985) notion of yardstick competition, where local monopolies are rewarded or punished depending on their relative performance compared to their benchmark. The benchmark is also referred to as the cost norm, the shadow firm, or simply the yardstick. Shleifer (1985) shows that if the heterogeneity is accounted for correctly and completely, the equilibrium outcome is efficient. In the absence of the real market competition, the local monopolies are forced to compete against each other in a virtual market created by the regulator.

Practical applications of yardstick competition in the energy sector are usually based on either variable cost or total cost benchmarking (cf., e.g., Haney and Pollitt, 2009). Both approaches have their shortcomings. The variable cost benchmark completely ignores the fixed capital, creating a strong incentive for the regulated firms to substitute variable inputs

[1] Other examples of network industries in the energy sector include natural gas transmission and distribution networks as well as district heating and cooling. Examples of network industries in other sectors include the water and sewage systems, roads and railroad tracks, and telecommunication networks.

by fixed capital in order to look more competitive. Therefore, application of the variable cost benchmark can result as over-investment, and hence further contribute to the capital bias known as the Averch-Johnson effect (Averch and Johnson, 1968). In contrast, the total cost benchmarking implicitly assumes all costs to be variable costs, ignoring the risk of investment in fixed capital.[2] In reality, adjusting the transmission capacity is costly and time consuming, and once the investment is made, based on the knowledge and information at that time, it cannot be easily recovered. A problem of the total cost yardstick is that it punishes owners for such investments that with hindsight turn out to be inefficient. The distribution firms face a risk that some parts of their grid become obsolete if a major buyer or seller of electricity shuts down.[3] Since such risks are beyond the control of the distribution firm, even a threat of ex post punishment may reduce incentive to invest in the grid.

Today, the grid operators around the world face a need for massive capital investments in order to strengthen the grid to sustain extreme weather events caused by climate change, to adapt to the changing structure of power generation towards small-scale decentralized production (e.g., wind and photovoltaics) as well as to changing patterns of consumption related to digitalization (consider, e.g., the internet of things and electric vehicles). On the other hand, emerging smart grid technologies and improved batteries and other types of energy storage offer potential for more efficient management of the power

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[2] Dalen (2004) examines in theory how firms' investment incentives are affected by yardstick competition. He finds that yardstick competition increases the incentives for firm-specific investments but lowers the incentive for industry-specific investment.

[3] For example, suppose a new manufacturing plant requires a costly extension of the high-voltage distribution grid, but after a few years, the manufacturing plant is relocated and the power cable becomes obsolete.

system, but adopting such technologies requires major capital investment. At the same time, most governments are struggling with the high level of public debt. To incentivize private investors to finance the necessary investments to transmission and distribution grids, the energy regulators face a difficult balancing act between reliability and affordability. The conventional yardstick and benchmarking regimes that either ignore the fixed inputs or treat them as variable inputs are inadequate tools to meet these challenges.

The objective of this paper is to provide several theoretical, methodological, and operational contributions to improve practical applicability of yardstick competition and benchmarking in the regulation of local monopolies. Our main theoretical contribution is to introduce a new regulation approach referred to as *conditional yardstick competition*. The proposed approach differs from the classic yardstick competition in that the opportunity cost of capital is treated as a fixed cost, and the local monopolies are forced to compete against the variable cost frontier, which determines the acceptable level of controllable operational cost, estimated conditional on the fixed input. We compare the conditional yardstick with the usual variable cost and total cost implementations of yardstick competition, and show that the conditional yardstick can effectively avoid both the over-investment associated with the variable cost benchmarking and the disincentive to invest associated with the total cost benchmarking.

Our methodological contribution is to help the regulator to estimate the variable cost frontier conditional on the fixed capital in order to implement conditional yardstick competition in practice. To put our methodological developments in context, we note that most previous practical applications of yardstick competition and benchmarking in energy regulation apply nonparametric data envelopment analysis (DEA) or stochastic frontier analysis (SFA) (see, e.g. Bogetoft, 1997; Haney and Pollitt, 2009; Bogetoft and Otto, 2011).[4] However, DEA is very sensitive to stochastic noise, whereas SFA builds upon restrictive functional form assumptions, which seriously limits the practical applicability of these methods in the real-world regulation (see Kuosmanen et al., 2013). To combine the appealing features of DEA and SFA into a unified estimation framework, Kuosmanen and Kortelainen (2012) developed stochastic nonparametric envelopment of data (StoNED), which contains both DEA and SFA as its special cases (Kuosmanen, 2008; Kuosmanen and Johnson, 2010; Kuosmanen et al., 2015). The StoNED approach has been used in the incentive regulation of Finnish electricity distribution firms since 2012 based on the work by Kuosmanen (2012).

This study extends the StoNED approach in several directions, by combining several recent developments in the nonparametric frontier estimation literature. We make use of the results by Kuosmanen and Johnson (2017) to estimate the variable cost frontier conditional on fixed capital in the general multi-input multi-output setting. The expected inefficiency estimated in a fully nonparametric fashion by applying kernel deconvolution (Hall and Simar, 2002), making use of panel data similar to Eskelinen and Kuosmanen (2013). We control for observed heterogeneity of firms and their operating environments by making use of the results by Johnson and Kuosmanen (2011, 2012). The main advantage of the proposed StoNED approach in the present context is that it can impose shape

[4] One notable exception is Yatchew (2001) who applies semiparametric econometric estimation to control for heterogeneity in the case of Ontario electricity distribution regulation.

constraints to ensure incentive compatibility of the estimated variable cost frontier, but also accounts for the observed heterogeneity and stochastic noise, similar to the standard econometric techniques. The innovative features of our model include the treatment of capital stock as a fixed input, treatment of interruptions as an undesirable output, and the use of the connection points per customer as an exogenous indicator of the operating environment.

The operational contributions of our study stem from the real-world application of the conditional yardstick regime in the incentive regulation of the Finnish electricity distribution firms in years 2016-2023, conducted in close collaboration with the Finnish Energy Authority. In this paper we share several practical insights gained through detailed discussion of the economic rationale behind the model specification used, including the specifications of the variable input, fixed input, desirable outputs, undesirable output, and the operating environment.

To put these theoretical, methodological, and operational contributions to the broader context of the energy market reform in its specific institutional setting, we briefly discuss the deregulation of the Nordic energy market. To demonstrate the real-world impacts of regulation on the transmission and distribution tariffs, we analyze the development of the average tariffs in the four Nordic countries, Finland, Denmark, Sweden and Norway in years 2014-2019. However, we must emphasize that neither the theoretical notion of conditional yardstick competition nor the proposed nonparametric estimation method are restricted to the special case of electricity distribution in Finland and other Nordic countries. Indeed, the developments described in this paper are directly applicable in the regulation of local monopolies in other countries and industries (e.g., district heating, natural gas transmission and distribution, water and sewage networks). We would argue that smarter regulation of network industries can contribute to lower risk premiums required by the investors, and help to achieve win-win solutions both in terms of reliability and affordability.

The rest of the paper is organized as follows. In Section 2 we discuss the deregulation of energy markets in the Nordic countries and introduce the Nordic revenue cap, which is the price control approach applied in the Nordic countries. Section 3 introduces conditional yardstick competition, and contrast its economic rationale with the conventional variable cost and total cost benchmarking. Section 4 specifies a variable cost function, describes the variables used in the analysis, and the estimation procedure used in conditional yardstick competition. Details are given for the 2016-2019 regulation period of the Finnish electricity distribution industry. Section 5 examines the impact of the conditional yardstick competition on the consumer prices in Finland in comparison with three other Nordic countries. Section 6 draws concluding remarks and discusses avenues for future research.

2. NORDIC ENERGY MARKET REFORM

The purpose of this section is to briefly describe the institutional background for the theoretical, methodological, and operational developments in Sections 3 and 4 (see Kuosmanen and Nguyen, 2020, for a more detailed discussion). The development of regulation methods in the Nordic countries has been covered in a large number of scientific articles (see, e.g., Agrell et al., 2005; Agrell and Bogetoft, 2010, Kuosmanen, 2012; Kuosmanen et al., 2013; Saastamoinen et al., 2017, and references therein), and the Nordic electricity sector has also served as a role model for many other European countries, for example, Germany (see, e.g., Agrell and Bogetoft, 2007). Further, the Nord Pool power exchange is frequently cited as successful examples of a liberalized competitive electricity market (e.g., Oseni and Pollitt, 2016).[5]

One of the key characteristics of the European energy market reform since the 1990s has been the division of the conventional vertically integrated utilities into three separate parts (a brief characterization of the market is indicated in parentheses):[6]

1) energy generation in power plants (competitive market),

2) high-voltage transmission over long distance (government monopoly), and

3) local distribution (many private and public firms with local monopoly).

The purpose of this division was to create a competitive market in energy generation and the retail trade of electricity, with free entry and exit, where both household and non-household customers can choose to buy electricity from any retailer, not restricted to the local utility monopoly.

The competitive reform of the retail market of electricity created pressure for the Nordic energy regulators to develop incentive regulation of their electricity transmission

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[5] First launched in Norway in 1993, Nord Pool expanded to Sweden, Finland and Denmark by the end of 1990s, and currently operates in 15 countries. For further information, see: https://www.nordpoolgroup.com/About-us/History/.

[6] Jamasb and Pollitt (2005) provide a more detailed discussion of the electricity market reform in Europe.

and distribution sectors, which remain natural monopolies subject to national government regulation. NordREG is an organization of the Nordic energy regulators with the stated aims to promote the development of efficient electricity markets in the Nordic area, consistent with the regulations at the EU level. In their comprehensive methodological report NordREG (2011), the Nordic regulators recognize that the real-world regulation schemes typically involve features from different approaches: "It is common to use combinations of [methods], for example a revenue cap regulation with inflation index and yardstick analysis in combination with bottom (minimum) and ceiling (maximum) rules on rate of return" NordREG (2011). This makes it challenging and also potentially misleading to try classify incentive schemes implemented for a specific industry in a specific country using the abstract categories discussed in the academic literature. The recent paper by Kuosmanen and Nguyen (2020) demonstrates that the Nordic revenue cap differs considerably from its usual meaning in the Anglo-American literature revenue (e.g. Mayer and Vickers, 1996; Jamison, 2007). In fact, the Nordic revenue cap turns out to be rather similar to the classic rate of return regulation, which is subject to the capital bias known as the Averch-Johnson effect (Averch and Johnson, 1968). In the following, we briefly discuss the economic rationale of the Nordic revenue cap, following Kuosmanen and Nguyen (2020).

Bernstein and Sappington (1999) argue that the purpose of regulation "is to replicate the discipline that market forces would impose on the regulated firm if they were present." Therefore, the competitive market equilibrium serves as a useful role model. It is well established in the microeconomic theory that market competition will eliminate any excess profits in the long run, driving the economic profit down to zero for all firms in the market equilibrium. Hence, in the competitive market equilibrium, we have

$$\textit{Total Revenue} = \textit{Variable Cost} + \textit{Fixed Cost}. \qquad (1)$$

That is, the revenue is exactly equal to the variable cost (including wages, materials, services etc.) plus the fixed cost (i.e., the opportunity to cost of capital, including both equity and debt) in the competitive market equilibrium. Note that zero economic profit does not mean zero accounting profit: a normal return on equity is included as a part of the fixed component.

The economic rationale of the Nordic revenue cap approach is to mimic the competitive market equilibrium (1) by setting the revenue cap, defined here as the maximum level of revenue that a monopoly can generate, equal to the total cost that is considered acceptable. That is:

$$\textit{Revenue Cap} = \textit{Acceptable Variable Cost} + \textit{Acceptable Fixed Cost} \qquad (2)$$

By controlling the total revenue of the monopoly firm, the regulation has direct effect on consumer prices that the monopoly firm can charge for its services. To set the appropriate level of the revenue cap, the regulator can use information and data from the input side to evaluate the firm's total cost.

An important feature of the Nordic revenue cap approach the clear distinction between the fixed and variable costs in equation (2). In the terminology of regulators, the variable cost is often referred to as operational expenditures (OPEX), and the fixed cost is referred to as capital expenditures (CAPEX), but the basic idea is the same.[7] In practice, the OPEX and CAPEX components are assessed separately.

To evaluate the acceptable level of fixed cost (CAPEX), the regulator estimates the opportunity cost of the monopoly's fixed assets. In finance, the capital asset pricing model (CAPM) is the standard approach to determine a theoretically appropriate required rate of return for a risky asset. The Nordic energy regulators estimate the weighted average cost of capital (WACC), which builds on the basic idea of CAPM but also draws a distinction between equity and debt. The acceptable fixed cost is calculated as the product of the regulatory asset base (RAB) and WACC percentage. While there are some differences in the specification of the capital based and WACC across Nordic countries, in broad terms, a similar approach is applied in all four countries mentioned above, both in transmission and distribution industries. We will briefly elaborate the practical application of CAPM in Section 3.3.

To evaluate the acceptable level of variable cost (OPEX), most Nordic countries apply best-practice benchmarking in one form or another to provide incentives for efficient operation (e.g., Agrell and Bogetoft, 2010),[8] but the methods and incentives different considerably both across countries and between the transmission and distribution sectors. We next briefly review the evolution of the Finnish electricity distribution industry and the benchmarking methods applied by the Finnish Energy Authority to determine the OPEX

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[7] The uncontrollable part of OPEX is often treated as a fixed cost. In addition to OPEX and CAPEX, the Nordic revenue cap typically includes additional components such as investment allowances and quality incentives. See NordREG (2011) for further discussion.
[8] Benchmarking is also applied by many other regulators around the world (see, e.g., Jamasb and Pollit, 2005; Haney and Pollitt, 2009; Goto and Sueyoshi, 2009; Bogetoft and Otto, 2011).

norm.[9] The new methodological developments of the present study are discussed in more detail in Section 4.

Historically, the Finnish electricity distribution firms were typically municipality owned and operated utilities. Major consolidation of the industry started in the 1990s as many municipalities privatized their distribution networks, and large international energy companies started to acquire and merge the firms to form larger grid firms. There were 130 local distribution monopolies in 2005, but only 87 remained in operation in 2018. The need to finance major capital investments has been one of the key motivation behind privatization and consolidation (e.g., the regulatory asset base (RAB) of the 87 distribution firms amounted to €11.3 billion in 2018 according to the Finnish Energy Authority). Today, the Finnish electricity distribution firms are attractive low-risk assets for international institutional investors such as pension funds and insurance companies. [10]

The Finnish Energy Authority has systematically applied benchmarking to all distribution firms on a regular basis since 2005. In the first regulation period (2005-2007), the Finnish Energy Authority defined the acceptable level of OPEX based on the input-oriented DEA model with a single input (total expenditure, TOTEX) and three outputs, based on Korhonen and Syrjänen (2003). The output variables introduced by Korhonen and Syrjänen are still in use today. The firm-specific DEA efficiency score was computed based

[9] For a more detailed description, see the website of the Finnish Energy Authority: https://energiavirasto.fi/en/pricing-regulation.

[10] For example, Finland's second largest distribution firm Elenia was traded in 2017 for approximately €3.6 billion. The sellers included Goldman Sachs Infrastructure Partners, 3i Infrastructure, and Finnish pensions insurance company Ilmarinen. The buyers included Allianz Capital Partners, Australian infrastructure investor Macquarie, and the State Pension Fund of Finland. Source: Reuters: https://www.reuters.com/article/us-elenia-sale/finnish-power-grid-company-elenia-sold-to-allianz-macquarie-idUSKBN1E72N8.

on the total expenditure (TOTEX = OPEX + CAPEX). Peculiarly and without explaination, the TOTEX efficiency was subsequently translated to a monetary OPEX target. For the second regulation period (2008-2011), parametric SFA estimation of the efficiency score was used in parallel with DEA (Syrjänen et al., 2007). The OPEX target was calculated based on the average of DEA and SFA efficiency percentages, which were estimated based on TOTEX. The third regulation period (2012-2015) introduced major methodological reforms based on Kuosmanen (2012). The OPEX target was directly estimated from OPEX data using stochastic nonparametric envelopment of data (StoNED) method (Kuosmanen and Kortelainen, 2012), which combines the attractive properties of DEA and SFA to a unified estimation framework.

The main lesson from the above discussion is that the regulator can systematically collect data of costs and outputs for all distribution firms, which offers the regulator a certain type of informational advantage over a single firm that has only access to its own information. Whereas the regulation theory conventionally emphasizes the informational advantage of the firm over the regulator (e.g., Laffont and Tirole, 1993), by applying a common cost frontier as the industry-wide benchmark, the regulator can at least partly offset the lack of private information by the firm. With the modern tools of econometric, statistics, and data analytics, such a rich panel data allows the regulator to set cost targets with reasonable accuracy. We return to our proposed developments in the statistical estimation of the cost frontier in Section 4.

Note that the Finnish regulator has systematically applied the variable cost norm as the benchmark. If the yardstick competition was extended to the CAPEX, it might discourage the necessary capital investments and compromise reliability of electricity supply. In our experience, under-investment is typically a great concern to regulators. In contrast, economists are typically concerned about the over-investment: if the regulated monopoly can influence the CAPEX norm by its own choices, the door is open for the Averch-Johnson effect. The next section introduces the conditional yardstick approach as a novel conceptual approach to solve this long-standing problem.

3. CONDITIONAL YARDSTICK COMPETITION

3.1 Variable Cost Versus Total Cost

Yardstick competition was introduced by Shleifer (1985) as a theoretically appealing regulatory instrument where local monopolies such as electricity distribution firms are forced to compete in a virtual market place in the absence of a real market competition. The term yardstick refers to the use of a cost norm, constructed by suitably averaging the observed costs of similar firms. The regulated firms are rewarded or punished depending on their relative performance against the cost norm. Shleifer (1985) shows that if the heterogeneity is accounted for correctly and completely, the equilibrium outcome is efficient. Yatchew (2001) provides an insightful discussion regarding the use of flexible nonparametric and semiparametric regression and robust median and quantile regression techniques to account for heterogeneity in the context of incentive regulation of electricity distribution firms.

While the regulation theory provides useful insights, it is far from obvious how yardstick competition should be operationally implemented in the real-world regulation.

While many energy regulators apply some elements of the yardstick competition, or a closely related notion of benchmark regulation, most academic studies operate at a relatively abstract level, ignoring many practical aspects of the real-world regulation. For example, theoretical treatments of yardstick competition typically ignore the distinction between the variable cost and the fixed cost.

In the real-world regulation, two common approaches to implement the yardstick competition in practice is to define the cost norm based on the total cost or the variable cost. The total cost approach treats the capital assets as variable inputs, whereas the variable cost approach ignores the fixed costs completely. Both approaches have their own shortcomings.

The situation is graphically illustrated in Figure 1. **[[fig 1 about here]]** The substitution possibilities between the variable input (on the horizontal axis) and the fixed input (on the vertical axis) are governed by the input isoquant (the convex curve with a solid line). The downward sloping broken line is the isocost line; the slope of the isocost line depends on the opportunity cost of capital. If the regulator can correctly estimate the input isoquant and the opportunity cost of capital (e.g., by using CAPM), then the total cost yardstick is the cost minimizing point indicated as the TOTEX norm. In contrast, the variable cost is minimized in the point indicated as the OPEX norm.

The black dot in the figure indicates a hypothetical firm subject to yardstick competition. If the yardstick is based on the TOTEX norm, then the regulated firm in this example would have to decrease its fixed cost in order to adjust its cost structure to meet the TOTEX norm. However, adjusting the fixed input is not possible in the short run. In the long run, the example firm has an incentive to decrease its capital input, which could delay investments. Like in the real markets, competition in the virtual market set up by the regulator would reward those firms that make profitable investments and punish firms for wrong investment decisions. Note that the regulator must estimate the TOTEX norm one way or another, which involves a risk of underestimation. Obviously, the regulated firms would try to influence the regulator and argue for a higher TOTEX norm. Shleifer (1985) notes that "it is essential for the regulator to commit himself not to pay attention to the firms' complaints and to be prepared to let the firms go bankrupt if they choose inefficient cost levels." However, the lifetime of electricity transmission and distribution assets typically spans several decades, and once the capital investment is made, based on the knowledge and information at that time, it cannot be easily recovered. Therefore, punishing grid firms for investments that were made decades ago, which with hindsight turn out to be inefficient, may seem unfair. In fact, even a threat of such punishment may already reduce the necessary investment in the grid.

In contrast, if the yardstick competition is restricted solely to the variable cost, with no restrictions to the capital input, then the use of the OPEX norm would give a strong incentive to substitute variable inputs by fixed capital, leading to over-investment. In Figure 1, the OPEX norm is the point in the top left corner of the diagram that minimizes the variable cost. Note that if the opportunity cost of the fixed capital approaches to zero then the TOTEX norm converges to the OPEX norm. Of course, achieving the OPEX norm is not possible in the short run because adjusting the fixed assets is time consuming. However, those firms that have overinvested in the past would benefit from the OPEX regulation. In the long run, yardstick competition based on the OPEX norm would drive all firms to overinvest to avoid bankruptcy. This is the main shortcoming of the variable cost yardstick regulation that ignores the fixed cost. To avoid these shortcomings, we propose an alternative approach where the variable cost norm is specified conditional on the fixed input. We refer to this new approach as the conditional yardstick. In Figure 1, the conditional yardstick is illustrated by an arrow that projects the regulated firm to the input isoquant, maintaining the current level of the fixed input. We discuss the formal specification of the variable cost function and its empirical estimation in more detail in Section 4; in this section we introduce the concept and discuss its economic rationale.

Since the conditional yardstick does not involve any adjustment to the fixed input, the variable cost norm is achievable in the short run. We see this as a major advantage of the conditional yardstick over the previous yardstick regimes that apply the OPEX or TOTEX norm. Stated differently, the conditional yardstick does not incentivize firms to substitute variable inputs by fixed capital nor punish regulated firms for their past investment decisions that turned out to be inefficient: the capital stock is treated genuinely as a fixed input.

Note that by modeling fixed and variable inputs separately, we also avoid the need to estimate the opportunity cost of the fixed capital. In other words, we can specify the OPEX norm as a function of the capital stock directly, without converting the stock of capital to a yearly flow of money required to sustain the stock, requiring additional assumptions about the applicable interest rate and depreciation. Note that if the opportunity cost of capital differs across the regulated firms, then the slope of the isocost line in Figure 1 would differ across firms, which would lead to different optimal solutions to minimize the TOTEX.

The following simple example illustrates the difference between the stock and the flow of capital. Suppose the capital stock (RAB)[11] of a firm is worth one billion euros. In the conditional yardstick regime, the RAB can be directly used for estimating the OPEX norm. In contrast, the use of the TOTEX norm requires the conversion of the RAB to a yearly flow of money. Suppose the WACC is five percent per year. Thus, the yearly opportunity cost of one billion euros of capital is fifty million euros, so one could calculate the total cost as the sum of variable cost and the fixed cost of fifty million. Notice that this aggregation is highly sensitive to the assumed WACC percentage. If the WACC was four percent instead of five, then the capital cost added to the variable cost would decrease by ten million. As discussed in Section 3.3, valuation of the opportunity cost of capital is not an easy task in the case of monopoly firms that are not traded in the stock market and thus makes our fixed cost dependent on an uncertain estimate. This example illustrates that a rather innocent one percent point change in the regulatory WACC percentage can have a major impact on the TOTEX. By separating the variable cost and fixed cost, we can model the capital input as the stock variable (i.e., RAB) without a need to convert it to a yearly monetary flow (i.e., RAB×WACC). We see this is a notable practical advantage of the conditional yardstick approach.

[11] We use the term capital stock and RAB interchangeable.

3.2 Ex Ante Versus Ex Post Yardstick

One important practical question in the implementation of the yardstick competition is whether the cost norm should be determined ex post after observing the realized cost levels, or announced in advance, so that the regulated firms can adjust their variable cost? The answer to this question can have a significant impact on the incentives of regulated firms.

In the literature of yardstick competition, Agrell et al. (2005) and Bogetoft and Otto (2011) emphasize the importance of giving the rules of competition in advance, but argue in favor of ex post determination of the cost norm based on observed outcomes of other firms. Uncertainty about the cost norm would force the regulated firm to operate with maximum efficiency to look competitive when the cost norm is determined. However, we would argue that the ex post yardstick directly increases the risk for the investor. Uncertainty about the cost norm will directly increase the risk premium required by the investor to take part in the yardstick competition.

Our proposal for the conditional yardstick competition differs from the previous ex ante yardstick regimes in that the variable cost function (represented by the input isoquant in Figure 1) that determines conditional yardstick is estimated ex ante using data accumulated in the previous periods. The variable cost function is communicated in advance to the regulated firms to allow sufficient time for the regulated firms to plan their long-term strategy and shot-term operational tasks over the next regulation period. We see conditional yardstick competition as a continuous process that, once started, continues indefinitely. Therefore, the yardstick can be recursively updated based on the empirical evidence accumulated since the beginning of regulation. That is, not only the performance in the previous period counts, as in the periodic performance review used by most European regulators, but all previous periods should be taken into account in the estimation of the variable cost frontier. The conditional yardstick can be forward looking in the sense that the yardstick announced for the next period can take into account the expected technical progress and possible additional requirements such as new technical standards.

When the regulated firms know the cost norm in advance for a given regulation period (e.g., the Finnish Energy Authority applies 4-year regulation periods), they have time to adjust their variable costs and plan their capital investments to meet the cost norm during the regulation period. This reduces risk of investment, leading to a smaller WACC requirement and greater confidence to invest. By design, the conditional yardstick is more investor friendly than the conventional yardstick regimes that tend to ignore the fixed cost and the risk for investor.

3.3 Acceptable fixed cost

As noted in Section 2, CAPM is the most standard approach to evaluate the market rate of return for risky assets. CAPM builds upon the mean-variance portfolio diversification model by Markowitz (1952), and was independently developed in the works by Treynor (1961), Sharpe (1964), Lintner (1965), and Mossin (1966). In CAPM, the expected rate of return on an asset consists of a risk-free return and a risk premium that depends on the systematic risk of the asset relative to the market portfolio. The standard approach to apply CAPM in energy regulation is to use a suitable government bond return as a proxy for the risk-free return, and estimate the systematic risk based on empirical data of utility stocks traded in the stock market to estimate the market return on equity in the industry. The opportunity cost of capital is subsequently obtained as the product of RAB and the weighted average cost of capital (WACC, %), based on the works by Modigliani and Miller (1958, 1963).

The WACC percentage is a regulatory decision that may be justified or debated based on empirical estimates of CAPM parameters, but which cannot be empirically tested. A difficulty of applying CAPM to divested European electricity grids is that such companies are virtually non-existent in the stock market.[12] Most energy companies traded in the stock markets around the world are integrated utilities that operate exclusively or mainly in energy generation, and may have some distribution activity as well. Energy generation firms operating in competitive markets are clearly more risky than electricity grids that are local monopolies, and therefore, investors of energy generating firms require a higher return on equity. If the risk premium is evaluated based on energy generation firms, then it clearly overestimates the risk exposure of the regulated monopolies. Indeed, the main risk for a regulated monopoly is the regulation risk: the return on equity is determined by the revenue cap and the related incentives defined by the regulator. If the investors view the regulation as credible and predictable, they are willing to accept lower risk premium, and

[12] The discounted cash flows methodology provides an interesting approach to valuation, see Alma and Karan (2017) for an application to Turkish electricity distribution firms.

hence lower return on equity. This would allow the regulator to decrease the WACC parameters, which will eventually benefit the consumer in terms of lower tariffs.

Another interesting observation concerns the frequency of updating the WACC percentage. In the Finnish regulation model, for example, the WACC percentage is updated yearly. However, the yearly update only concerns the risk-free return, while the risk premium is only updated when the regulation period changes every four years. Ironically, the only source of risk regarding the WACC during a regulation period therefore concerns the *risk-free interest rate*. Since the Finnish government bond rates have been at very low level (sometimes even negative) after the financial crisis in 2008, the Finnish Energy Authority has responded by applying a long-term average of the government bond returns as the risk-free interest rate, but also by increasing the risk premium.

Finally, if firms are free to invest unlimited amounts of capital with the constant return equal to the WACC percentage, this can lead to overinvestment. Kuosmanen and Nguyen (2020) demonstrate that the Nordic revenue cap regime is not immune to the capital bias, known as the Averch-Johnson effect (Averch and Johnson, 1962). That is, if the WACC percentage is greater than the opportunity cost of capital in the financial markets, a profit maximizing monopoly has incentive to exploit the regulation premium and overinvest. While the conditional yardstick competition can eliminate the capital bias of the OPEX norm, the Averch-Johnson effect remains. Fortunately, the numerical simulations by Kuosmanen and Nguyen (2020) suggest that the Nordic revenue cap can meet most of its intended objectives despite the capital bias.

To alleviate the Averch-Johnson effect, we propose to draw a clear distinction between the accounting asset base of the monopoly firm and the RAB. While the monopoly controls its accounting assets, the regulator controls which assets are acceptable to the RAB, which together with the WACC determines the acceptable fixed cost. RAB can be controlled by so-called "command & control" measures either ex ante or ex post, possibly both. An example of ex ante control mechanism is to require the regulated monopoly firm to apply for regulator's approval before making significant new investments to the power grid. Any investment that was not approved by the regulator would not be counted in the RAB. Another example of ex ante controls is to specify in advance which type of network investments are acceptable to the RAB. If the regulator suspects manipulation, it could also apply ex post revisions to the RAB. If the regulator can prove that the monopoly has invested in "gold-plating" to take advantage of the regulation premium, it could remove such investment from the RAB, and hence leave those investments uncompensated. Clearly communicated ex ante controls and a threat of ex post revisions to the RAB can at least dampen, if not completely eliminate the Averch-Johnson effect.

4. VARIABLE COST FUNCTION

The variable cost function is the key instrument of conditional yardstick competition. Given the fixed cost and the operational environment, local monopolies are forced to compete against their "shadow firms", characterized by the variable cost frontier. Therefore, this section is devoted to specification and estimation of the variable cost frontier.

A general econometric model of variable cost frontier applied in the conditional yardstick regime of Finnish electricity distribution networks can be formally stated as [13]

$$\ln x_i = \ln C(\mathbf{y}_i, \mathbf{b}_i, K_i) + \boldsymbol{\delta} \cdot \mathbf{z}_i + u_i + v_i \qquad (3)$$

where x_i is the observed variable cost of firm i, C is a monotonic increasing and convex cost function satisfying constant returns to scale, $\boldsymbol{y}_i$ is the vector of output variables produced by firm i, $\mathbf{b}_i$ is the vector of undesirable outputs produced by firm i, K_i is the capital stock of firm i, $\mathbf{z}_i$ is the vector of contextual variables that characterize the operating environment of firm i, $\boldsymbol{\delta}$ is the parameter vector that describes the effects of contextual variables on variable cost, u_i is a non-negative inefficiency term, and v_i is a random noise term. More detailed specification of the variables will be discussed in Section 4.1 and the estimation will be discussed in Section 4.2. Note that model (3) is essentially a semi-nonparametric partially linear model that contains a nonparametric cost frontier C that is subject to shape constraints, and a parametric linear regression part with an asymmetric composite error term (see Johnson and Kuosmanen, 2011, 2012, for more detailed discussion). For simplicity, the model is stated as a cross-sectional model with no time dimension, but it easily extends to the panel data setting (see, e.g., Eskelinen and Kuosmanen, 2013).

Most benchmarking studies tend to focus on measuring or estimating inefficiency loss u. This focus reflects a methodological bias in the literature of efficiency analysis. In theory, we know that the efficiency measure or a distance function is an equivalent way to characterize the frontier, so in the deterministic setting where one assumes $v = 0$, which is

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[13] We follow the standard econometric notation and denote vectors in bold font. All vectors are column vectors, unless otherwise indicated.

typical of most benchmarking studies, it does not matter if we estimate *C* or *u*: if we can estimate cost frontier *C*, we can always recover *u*, and vice versa. This may explain why most benchmarking studies do not draw the distinction. However, a model with noise introduces some of the uncertainty that is prevalent in modeling and measuring of a complex production process like electricity distribution. The stochastic noise term *v* in the model introduces significant complexities to interpret the estimated model. It is not enough to estimate the frontier *C* in order to calculate *u*, and vice versa. The deterministic reasoning no longer applies.

For the purposes of the conditional yardstick, we need to indicate the regulated firm *i* the cost level of a shadow firm that operates in the same environment, satisfying the same demand for output, endowed with the same capital stock. That is, our objective is to provide each firm the estimated cost norm

$$\hat{C}(\mathbf{y}_i, \mathbf{b}_i, K_i) \cdot \exp(\hat{\boldsymbol{\delta}} \cdot \mathbf{z}_i) \qquad (4)$$

where the hats (^) on top of function *C* and parameter vector **δ** refer to the estimated cost frontier and the parameter estimates. Expression (4) indicates the efficient level of variable cost given the capital stock, the good and bad outputs, and the operating environment of firm *i*. This cost norm defines the cost level of the "shadow firm" with which firm *i* needs to compete. Under the constant returns to scale assumption, the productivity of the shadow firm is unaffected by the scale of operations. Or stated differently, the regulation structure provides no benefits to the firms for operating at a particularly scale, rather the firms operating at the most optimal scale will be closest to the cost frontier. Note, the presence of an inefficiency term *u* is explicitly recognized in model (3), and considered in estimation of the cost frontier *C*. Even if we do not measure inefficiency explicitly, it is implicitly present, and not assumed away.

Recall that frontier *C* is estimated using a sample of *n* observations, which allows one to *average out* the effects of random noise across all observations in the sample. In contrast, estimation of the firm-specific inefficiency term u_i is dependent on a random outcome of the individual firm *i*, making it impossible to average out the noise.[14] Importantly, cost frontier *C* can be estimated without making arbitrary distributional assumptions concerning inefficiency term *u*, see Section 4.2 for details. To our knowledge, our work is the first real-world application of the nonparametric kernel deconvolution estimation method. In our view, accounting for noise without strong parametric distributional assumptions is a vast improvement over the existing benchmarking methods applied in the regulation practice.

Finally, our experience suggests that it is very difficult to implement regulatory reforms if the regulated firms strongly oppose the change. Benchmark regulation is often resisted because firms do not want to be labeled as inefficient. Instead of labeling firms as inefficient, by introducing the conditional yardstick provides a more constructive profit-seeking incentive to improve efficiency, which can be more acceptable approach for the regulated firms. We consider this as a notable psychological advantage of the proposed conditional yardstick competition over the conventional benchmark regulation regimes that label firms as inefficient and set efficiency improvement targets.

[14] In the panel data setting where one observes the same firm over multiple time periods, it is possible to average out noise if one is willing to make a rather strong assumption that inefficiency is constant over time (or alternatively, follows some specific parametric trend).

4.1 Model Variables

In this section we take a more detailed look at the model variables: inputs, outputs, and contextual variables. Specifically, the rationale of variables used in the Finnish electricity distribution cost frontier model applied during the 2016-2019 regulation period, and the 2020-2023 regulation period is discussed with brief comments on the past revisions of the model variables (a brief description of the evolution of benchmarking in the Finnish regulation model is presented in the Appendix). The variables are:

Inputs:

Variable input:

x = Controllable operational expenditure (COPEX, €)

Fixed input:

K = Capital stock (replacement value, €)

Outputs:

Desirable outputs $\mathbf{y}$:

y_1 = Energy supply (GWh, weighted by voltage)

y_2 = Network length (km)

y_3 = Number of use points

Undesirable output:

b = Outages (hedonic damage cost, €)

Contextual variables:

z = Connection points / Use points

Clearly, appropriate specification of inputs, outputs and contextual variables is critical for the successful application of conditional yardstick competition. Observing electricity distribution industry in a variety of countries, we find that different regulators apply different variable specifications. The same applies to a large extent to the academic literature that provides surprisingly little guidelines for the choice of input-output variables. The purpose of the following discussion is to share some insights gained in Finland.

4.1.1 Variable input

The conditional yardstick regime forces the local monopolies to compete in terms of the variable input x, which is the dependent variable on the left hand side of equation (3). In the Finnish regulation model, x is defined as the controllable operational expenditure (COPEX, €).[15] This variable is primarily labor and material costs. Regarding labor input, note that many distribution firms outsource their maintenance tasks to subcontractors: the service fees of subcontractors are also included in COPEX, allowing distribution firms complete freedom to decide whether it is more cost efficient to outsource or hire staff to perform these tasks.

[15] The term "controllable" refers to the fact that some operational expenses are beyond the control of local distribution firms. These include, for example, high-voltage transmission fees charged by the national transmission monopoly. Such uncontrollable variable costs are passed through to the retail tariffs directly, and are not included in the estimation of the variable cost frontier model.

An important caveat in the use of COPEX concerns regional differences in labor costs. Wages tend to be higher in larger cities than in rural areas where also the cost of living is lower. However, it is very difficult to get reliable labor cost data at a regional level for a specific sector such as electricity distribution. Our empirical strategy is to control for the observed heterogeneity in terms of urban versus rural operating environment by means of the output variables $\mathbf{y}$ and the contextual variable z. Since the regression model (3) estimates the impact of observed heterogeneity on COPEX, it also indirectly captures possible regional differences in wage rates. For example, the impact of network length does not only reflect the direct cost of installing power cables, it also captures any indirect influence from unobserved factors that might correlate with it, for example, the rural operating environment with thicker forest cover and lower wage rate.

From econometric point of view, the fact that there is unobserved heterogeneity such as regional wage differences that is not explicitly controlled for in the model should alarm one to worry about the omitted variable bias. Indeed, if network length correlates with rural operating environment and hence with wage rate, then the regression model will yield biased estimates of the marginal operational cost of the network length. In contrast to typical econometric modeling exercise, the main purpose of our estimation is not to identify the marginal effects of explanatory variables, but rather, explain COPEX by variables that characterize observed heterogeneity. That is, our main interest in the overall predictive power of the model. If the variables that represent observed heterogeneity can also capture unobserved heterogeneity of the operating environment, possible omitted variable bias in the coefficients of the regression model is not a problem as such if the model provides a good prediction of COPEX based on the observed variables.

4.1.2 Fixed Input

While the capital input K is taken as a fixed input that is not subject to yardstick competition, it is nevertheless important to take the capital input into account as an explanatory variable in the econometric model (3). Recall from Section 3.3 that by modeling fixed and variable inputs separately, we avoid the need to estimate the opportunity cost of the fixed capital and can use the stock of capital directly as our measure of the fixed input.

The Finnish Energy Authority measures the capital input K by the replacement value of the capital stock (€). To this end, the regulated distribution firms must provide detailed inventory of capital equipment installed in their distribution network, such as underground cables, overhead lines, and transformers. The list includes thousands of items. The regulator maintains a database of retail prices for such capital equipment, matching all components in the firms' list with the corresponding price estimate. The regulator calculates the replacement value by simply multiplying the quantities of items with their corresponding regulatory prices, and adding up the costs of all items together. Subsequently, the regulator calculates the RAB as the depreciation adjusted replacement value, to obtain the acceptable fixed cost as the product RAB × WACC, as discussed in Section 3.3. In other words, the replacement value of the capital stock is used as K in the variable cost function, but it also forms an intermediate step to calculate RAB and the acceptable fixed cost.

The economic valuation of the capital stock that consists of thousands of different items is a notoriously difficult task. While the replacement value method used by the Finnish Energy Authority has its limitations, it is less sensitive to manipulation by regulated companies than accounting based valuation of the fixed capital. For example, the use of the replacement value does not allow the regulated firms to influence the capital input by an arbitrary choice of the depreciation method. Of course, it would be possible to apply RAB instead of the replacement value as the measure of K in the variable cost function. By using the replacement value, the regulator ensures that the conditional yardstick does not reward the use of old equipment or punish those firms that invest in new equipment.

4.1.3 Desirable Outputs

Since the first regulation period starting in 2005, the Finnish regulation model for electricity distribution includes the same three output variables. The rationale of this specification is discussed next.

The main task of the distribution firms is to supply electricity to customers. Therefore, the actual supply of energy in GWh measures the actual demand for the primary service of the distribution firm. However, measuring the supply is complicated by the fact that supply takes place at different voltage levels. Households demand low voltage, whereas industrial customers require high-voltage electricity supply. Instead of modeling different voltage levels as separate outputs, the middle and high voltage transmission are aggregated to low voltage transmission by using the average transmission tariffs as weights. In practice, high voltage transmission is cheaper than low voltage transmission, and this is reflected in the tariffs charged by the distribution companies. For example, in the 2016-2019 regulation period, the following weights are used: low voltage (0-0.4 kv) weight 1, middle voltage (1-70 kv) weight 0.432, and high voltage (110 kv) weight 0.271.

In addition to the actual supply, the latent demand also needs to be considered. In Finland, there are more than half-a-million recreational homes (summer cottages), most of which are nowadays connected to the electricity grid. While recreational homes are typically located in rural areas, requiring relatively long connections, their demand for electric power is typically restricted to the summer months. Therefore, the actual demand is complemented with two variables that reflect the latent demand: the network length (km) and the number of use points (i.e., the number of customers). These two variables help to better capture the heterogeneity of distribution firms. The ratio of network length to the number of use points is highest in rural areas and lowest in densely populated urban areas. While this triplet of output variables is well-established in Finland, other regulators prefer to use different output variables. Next, we will critically discuss the choice of output variables.

A common engineering argument against the use of actual electricity supply as an output would be that distribution networks are designed to sustain the peak load, and hence the total supply is not a relevant or adequate indicator. Therefore, some regulators use the peak load (e.g., the maximum hourly supply during the peak demand) as an output variable. Unfortunately, the peak load is very problematic from the incentive point of view. Clearly, using the peak loads as an output gives no incentive for the distribution firms to try shave the peaks, for example, by offering tariffs that encourage customers to shift their demand away from the peak hours. In fact, the use of peak load as an output incentivizes the distribution firms to try increase the peaks. The hourly supply during the demand peak can be easier to manipulate by the distribution firms than the total yearly supply.

The use of network length as an output has also caused some debate in the literature. Some authors argue that the network length is an input rather than an output (e.g., Filippini and Wild, 2001). While the logic of using the network length as a proxy for capital input in the railroad industry is clear, increasing the network length does not help a grid company to transmit more electric power to a given number of customers, but in fact, the opposite is true: transmitting power over a longer distance necessarily increases the power loss. Therefore, we argue that the *length* itself is not an input. In electricity distribution, the network length tends to correlate with the capital input, but it is only a rough proxy of RAB or the replacement value of the capital stock.

In the context of the Finnish regulation model, the network length serves as a proxy for the size of the service area. Indeed, some regulators use the service area (in km^2) as an output variable. In principle, the service area would be a better output measure because the network length is clearly an endogenous output that can be influenced by the distribution firm (within certain limits set by the regulator). In Finland, however, the service areas do not coincide with the municipality boundaries, and in one case the service area consists of two cities located 450 km apart from each other. Unfortunately, reliable measures of service area are not readily available in Finland.

4.1.4 Undesirable Output

To our knowledge, the specific approach to modeling of undesirable output is a novel innovation of the Finnish electricity distribution regulation. Models of undesirable outputs are usually applied in the context of emissions such as CO2 in energy production, but as the term "undesirable output" reveals, any unwanted side-product can qualify.

In electricity distribution, unintended failure of electricity supply is referred to as outages (or blackouts). Note that outages decrease the supply of electricity, as measured by output 1, below the actual demand. However, the marginal social cost of outages far exceeds the distribution tariff. A modern society is dependent on electricity supply that even a short outage will cause problems, while longer outages can potentially cost lives. The Finnish Energy Authority applies hedonic estimation of external damage cost due to outages. The model takes into account both the number of outages over the time span of one year and the duration of outages, translating the technical data of outages to a hedonic cost estimate (in €). Note that this outage cost is a purely abstract construct used only for regulation purposes: the hedonic outage cost is generally much higher than the actual monetary compensation that distribution firms pay to customers that suffer from outages. Therefore, we will refer to the hedonic outage cost as outage externality. Note further that the actual monetary compensation for outages is also included in the variable input (COPEX).

Due to the climate change, both frequency and intensity of weather-related outages has increased during the past decade. The Finnish government reacted to this challenge: in 2013 the Finnish parliament passed a new law that requires distribution firms to significantly improve the weather resistance of electricity grid by the year 2028. The storm related outages were also frequently covered in popular media motivating the Finnish Energy Authority to rethink outage externality modeling in the variable cost frontier model. Note that incentive regulation punishes distribution firms for outages both on the output side (decrease of y_1 below actual demand) and on the input side (monetary compensation for outages increases COPEX), but does not recognize that a certain level of outages may be unavoidable.

In the 2016-2019 and 2020-2023 regulation periods, the outage externality is treated as an *undesirable output* jointly produced with the desirable outputs. From conceptual point of view, outage externalities are similar to pollution. Nobody wants outages to occur, but sometimes unavoidable outages occur due to major storms, heavy wind, falling trees, heavy snow, and other such extreme weather events. As the scale of distribution increases, the outage externalities also tend to increase.

By modeling the outage externality as an undesirable output, the marginal effect of outages on variable cost can be either positive or negative. In fact, the impact of outages on COPEX becomes a U-shaped convex curve. A distribution firm that has relatively low outage externalities compared to the scale of its activity is rewarded as higher COPEX that can be used for both avoiding outage damages (e.g., cut trees and branches near power lines before they fall down and cause damage) and for quickly repairing damages when outages occur. For an average firm, the acceptable COPEX is relatively low as the average firm does not spend on avoiding outage damages but also does not suffer from extreme weather shocks. For distribution firms that are unfortunate to sustain major weather events causing large-scale outages, the acceptable COPEX increases in order to allow the distribution firm to pass on a part of the reparation cost to the customers. In other words, decreasing outage externalities are rewarded by higher COPEX under normal operational conditions, but if the outage externalities increase beyond certain critical threshold, then the firms are not punished for outages but are rather allowed to spend more operational costs for repairing the damage.

The new approach to model outage externality as an undesirable output was appreciated by both the regulator and the regulated companies. While storm damages continue to cause outages, the distribution firms have clearly improved their operations and communication with their customers. For example, distribution firms observe weather forecasts and keep their repair staff alerted and ready to respond if heavy snowfall or stormy winds are expected. Strengthening the grid to meet the standards required by legislation is also decreasing the outages.

4.1.5 Contextual variables

While the output variables already capture heterogeneity of operating environment relatively well, particularly with respect to urban versus rural areas, both the regulator and the distribution firms felt that a sharper distinction between suburban areas and city center was required. For the 2012-2015 regulation period, the Finnish Energy Authority included the percentage of underground cabling (%) in the middle voltage network as a contextual variable. This variable takes the value of 100% in Helsinki, and decreases towards zero in rural areas. Adding this contextual variable improved the empirical fit of the model, helping to explain away some of the observed heterogeneity. In statistical tests, the underground cabling was found to have a significant positive impact on operational cost.

However, the underground cabling is clearly an endogenous variable. Partly due to the legal requirement to improve weather resistance of electricity grid, and also partly due to the incentives set by the COPEX regulation, the percentage of underground cabling increased significantly during the 2012-2015 regulation period. This raised some concerns that the explanatory power of this contextual variable will likely decrease in the future. Moreover, rewarding underground cabling over other technologies to strengthen the grid in the incentive regulation might lead to cost inefficient choices. Therefore, the regulator decided to replace the endogenous underground cabling percentage by a more exogenous contextual variable for the 2016-2019 and 2020-2023 regulation periods.

Many alternative contextual variables and their combinations were systematically tested. However, it proved surprisingly difficult to find variables that yield coefficients with the correct sign, are statistically significant, and are exogenous to firms. Many candidate variables that seemed promising from the outset (e.g., snow depth, soil types, or length of underwater cables) proved disappointing in practice.

Eventually, both the statistical testing and engineering logic pointed towards using the ratio of connection points and use points as the contextual variable. The logic of this variable is the following. In urban areas there are residential buildings that consists of multiple apartments. Each building has only one connection point but multiple use points. In Helsinki, this ratio takes the value of 0.1, which means that there are ten use points per each connection point. In rural areas there are no apartment blocks but only detached houses, for which the number of use points is the same as the number of connection points. For many rural distribution firms, the ratio of connection points to use points is equal to one. Since the local electricity distribution firm has little effect on the structure of housing choices within their service area, this contextual variable can be considered exogenous, and adding it to the variable cost frontier model significantly improves the explanatory power.

Note that the percentage of underground cabling has slightly better explanatory power as a contextual variable than the ratio of connection and use points. The decision to replace the contextual variable was not made based on statistical fit, it was solely based on the exogeneity considerations and the fact that the ratio of connection and use points is neutral to alternative technological solutions to improve weather resistance of the grid.

In the 2012-2015 regulation period, the vector of contextual variables also included a time trend, which implied approximately 2% yearly productivity growth intended to model technical progress. During the 2012-2015 regulation period, the variable cost frontier was yearly shifted downward by this factor to incentivize the distribution firms to improve their productivity and pass on the resulting cost savings to the customers.

For the 2016-2019 and 2020-2023 regulation periods, the time trend was excluded. There were two reasons for this choice. First, the distribution firms argued that the new legislation from 2013 that requires improving weather resistance of the grid presents such a technological discontinuity that the past evidence of 2% productivity growth no longer applies. Second, in the statistical analysis preceding the 2016-2019 and 2020-2023 regulation periods, the empirical estimates of the time trend tended to yield a negative coefficient in most model specifications considered.[16] A negative time trend is very likely

[16] Dimitropoulos and Yatchew (2017) similarly report productivity decline in the electricity distribution industry of Ontario.

due to the change of legislation in 2013 to improve weather resistance, but also the frequent storm damages themselves may have influenced the productivity development. Instead of blindly accepting a negative coefficient for the time trend based on statistical evidence, which would allow the regulated firms increase their variable cost in the future, the regulator decided to simply eliminate the time trend, as the firms had demanded. In our interpretation, giving up the 2% productivity growth target was a compromise solution where the regulation gets tighter in some respects (e.g., making OPEX-norm conditional on K) but more generous in some other aspects.

4.2 Estimation

Econometric model (3) can be categorized as a partially linear semi-nonparametric model, which includes a non-parametric cost function, a linear function of contextual variables and a composite error term. The classic benchmarking methods such as DEA and SFA are clearly not suitable for estimating this model: model (3) is rich with elements such as undesirable outputs and noise that require a general enough estimator that can incorporate the best features of both DEA and SFA in a unified framework. In the 2016-2019 regulation period, the Finnish Energy Authority applies the StoNED method to estimate model (3) using unbalanced panel data for years 2007-2014 (updated in 2019).[17] Here we summarize the primary details and direct the reader to Kuosmanen and Johnson

[17] The nonparametric shape-constrained estimation approach developed in the works by Kuosmanen (2008), Kuosmanen and Johnson (2010), Kuosmanen and Kortelainen (2012), Kuosmanen et al. (2015) is referred to as the StoNED method in the literature, which is also the term used by the Finnish Energy Authority.

(2017) for a detailed description of this procedure. Estimation consists of three steps, to be described next.

Step 1: Estimate the conditional mean of variable cost x, conditional on model variables $\mathbf{y}$, b, K, and z. That is $E(x \mid \mathbf{y}, b, K, z)$. This is done by semi-nonparametric convex regression. In step 1, we ignore the fact that the composite error term does not have a zero mean; we will deal with that issue in Step 2 below. The purpose of the first step is to capture the shape of the variable cost frontier (see Kuosmanen and Johnson, 2017, for further details)

Step 2: Given the conditional mean of variable cost, the next step is to estimate the expected inefficiency loss $E(u)$. For the purposes of regulation, a distribution free approach to estimate expected inefficiency loss would clearly be desirable. Such an estimator has been proposed by Hall and Simar (2002). Their kernel deconvolution estimator, identification of the expected inefficiency loss is based on kernel density estimation of the density function of the composite error term. Hall and Simar (2002) show that the first derivative of this density function is proportional to that of the inefficiency term in the neighborhood of $E(u)$. This is due to the fact that the density of u has a jump discontinuity at zero. Therefore, a robust nonparametric estimator of the expected inefficiency loss is obtained by identifying a point that maximizes the first derivative of the kernel density estimator of the composite error term.[18]

[18] Hall and Simar (2002) demonstrate by Monte Carlo simulations that the estimator performs reasonably well, even though statistical consistency of the estimator cannot be established under the general assumptions considered in their study. For the purposes of regulation, a robust nonparametric estimator that does not depend on arbitrary distributional assumptions is preferred over parametric alternatives.

Step 3: Having estimated the expected inefficiency loss E(u) = $\hat{\mu}$ in Step 2, the conditional mean of the variable cost estimated in Step 1 can be shifted downward to obtain an estimator of the efficient cost level. For an observed firm *i* in period *t*, our estimate of the efficient level of variable cost is given by

$$\hat{\phi}_{it} \cdot \exp(\hat{\delta} \cdot z_{it} - \hat{\mu}) \tag{5}$$

where $\hat{\phi}_{it}$ is the estimate of the cost frontier given both the good and bad outputs and the capital stock of firm *i* in period *t* obtained in Step 1, $\hat{\delta} \cdot z_{it}$ is the adjustment for the operating environment obtained in Step 1, and $-\hat{\mu}$ is the adjustment for the expected inefficiency loss obtained in Step 2. While the efficient level of variable cost can be calculated ex post to all observations, the conditional yardstick competition requires a variable cost frontier that can be applied in the next regulation period. Therefore, it is necessary to extrapolate beyond the observed data points. Kuosmanen and Kortelainen (2012) propose to extrapolate beyond observed data points by using the smallest convex monotonic hull of the estimated frontier points.

The variable cost function and its estimation form a key component of the conditional yardstick competition methodology. In contrast to the conventional yardstick and benchmarking approaches that only compare performance to a single data point that is determined ex post, in the conditional yardstick approach the entire variable cost function serves as the benchmark. Once the variable cost frontier has been estimated, it can be communicated to the regulated firms in advance such that the firms can adjust their operational plans and investment decisions. In the Finnish electricity distribution regulation, the regulator provides a spreadsheet application that allows the distribution firms to easily calculate the OPEX benchmark at different levels of input and output variables, and hence anticipate how the benchmark changes as a result of possible changes in the outputs, the capital stock, or the operating environment.[19]

5. IMPACTS ON CONSUMER PRICES

The purpose of this section is to provide empirical evidence on the real-world impact of the regulatory reforms discussed in the previous section based on available data of electricity prices. Since the transmission and distribution tariffs charged by the local monopolies are subject to direct price controls by the government regulators, the observed tariffs are the outcomes of the regulation method applied. Therefore, the impact on customer tariffs is the ultimate test of any method that has been implemented in the real-world regulation.[20]

In Europe, Eurostat monitors the consumer prices of electricity to facilitate greater transparency of the electricity market and help promote further market integration across national boundaries. For the sake of comparability, the Eurostat price data includes both the price of electric power and the transmission and distribution charges (including fixed costs), but excludes all taxes. In addition, the average market price of electric power can be calculated for the four Nordic countries that participate in the Nord Pool power exchange.[21]

[19] The Excel application is available online at: https://energiavirasto.fi/hinnoittelun-valvonta.
[20] Kuosmanen et al. (2013) evaluate performance of the DEA, SFA, and StoNED benchmarking methods by means of empirical data and Monte Carlo simulations, demonstrating superior performance of the StoNED method.
[21] The bi-annual average market price of electricity in each country was calculated as the weighted average of the daily prices, weighted by the daily consumption.

Subtracting the average price of electric power and all taxes from the average consumer price of electricity, we obtain the average transmission, distribution and service charges of household and non-household customers as a residual. In other words, we can estimate how much the government regulated natural monopolies in electricity transmission and distribution charge their customers in the Nordic electricity market.

Table 1 reports the bi-annual average transmission, distribution and service charges of household and non-household customers in Finland (FIN), Denmark (DEN), Sweden (SWE) and Norway (NOR). **[[table 1 about here]]** In all four countries, the transmission and distribution has been divested from the competitive electrical energy market. In all four countries, there exist a relatively large number of local distribution firms, which may be owned by municipalities or private investors, and are subject to government regulation. However, detailed comparison of the regulation methods applied in different countries proves very challenging and falls beyond the scope of this paper.[22]

Following the Eurostat standards, Table 1 reports the average tariffs separately for the households (yearly consumption 2.5.-5 MWh) and non-household customers (yearly consumption 500-2000 MWh). Considering the household consumers, we find the lowest transmission and distribution tariffs in Denmark, excluding all taxes.[23] Finnish households paid on average eight percent higher tariffs than Danish households during this period, but

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[22] We refer to Agrell and Bogetoft (2010) and NordREG (2011) for further discussion, noting that the practical details of implementation differ across countries and tend to change over time in each country, which makes it difficult to compare the regulation regimes at a highly detailed level.

[23] When taxes are included, the Danish consumer prices of electricity were among the highest in Europe during this period, on par with the price level in Germany (on average 30 s/kWh in 2017), according to the Eurostat price statistics. In contrast, the Finnish consumer prices of electricity were among the lowest in Western Europe, at similar level to the densely populated Netherlands (only 16 s/kWh in 2017).

on average, the Finnish tariffs were considerably lower than those in Norway and Sweden. In all four countries, the transmission and distribution tariffs for households are larger than those for the non-household consumers: industrial energy supply typically occurs as high-voltage transmission that has a lower unit cost. For the non-household consumers, the average transmission and distribution tariffs were the lowest in Finland.

Note that the figures reported in Table 1 do not take into account differences in the operational conditions across countries. The high transmission and distribution tariffs in Norway may be partly due to the rough terrain with high mountains and steep fjords, which increase the cost of transmission and distribution compared to Denmark, which has a much larger urban population and shorter distances. In Finland, the long distances due to sparse population, relatively cold temperature in winter months, and trees falling down on power lines due to heavy wind or snowfall presents clearly a more challenging operating environment for power grids than the relatively densely populated Denmark. Located in the middle of Scandinavia, Sweden shares the operational conditions of all its neighbor countries, but the Swedish households paid considerably higher transmission and distribution tariffs than other Nordic customers in 2015-2017; the Swedish tariffs decreased notably in 2018, but remain above the price level in Finland and Denmark. Clearly, the differences in tariffs indicated in Table 1 cannot be solely explained by geographical conditions or the population density. The comparison of the average transmission and distribution tariffs across Nordic countries demonstrates that the incentive regulation in Finland yields considerably lower price level than in Sweden or Norway, reaching comparable price level with Denmark. Excluding tax increases, the average tariffs for the Finnish household consumers fluctuate over time, but show no increasing or decreasing trend, while the average tariffs of the non-household consumers have a clear decreasing trend.

By now, the conditional yardstick approach is generally accepted by the industry, and the Energy Authority continues to apply the methodology during the 2020-2023 regulation period. In contrast, the household consumers remain uninformed and skeptical. Note that the average tariffs reported in Table 1 do not reveal the increased dispersion of tariffs across distribution firms in Finland. Thanks to the developments described in Section 4, there has been significant improvements to better capture the heterogeneity of distribution firms and their operating environments. It naturally follows that firms operating in favorable environments must decrease their tariffs, whereas firms operating in adverse conditions are allowed to increase tariffs. This will naturally lead to increasing price dispersion across firms.

In particular, distribution firms that operate in sparsely populated areas have sharply increased their tariffs. The major price hikes by the two largest distribution firms, Caruna and Elenia that are largely owned by foreign investors, resulted as a public outcry in 2016. Since announced increases of the transmission tariffs tend to attract attention, whereas decrease in tariffs usually go unnoticed, the general public may have a biased perception of ever increasing tariffs, even though the available price statistics indicate that the average tariffs remain rather stable over time. To calm down the public outcry due to tariff increases, the Finnish government interfered by introducing a price cap, which restricts the tariff increase to the maximum level of fifteen percent per year. Clearly, the price cap is rather cosmetic as it can only delay the price increases to the future. However, the introduction of the price cap on the top of the conditional yardstick illustrates the risk of political intervention. Therefore, it would be important to better communicate the main principles and rationale of the incentive regulation to the policy makers and the public; this is clearly one area where the Finnish Energy Authority has room for improvement. We hope that this article might prove helpful in this respect.

6. CONCLUSIONS

Electricity transmission and distribution networks require massive investments to mitigate and to adapt to climate change, the changing structure of power generation, changing patterns of consumption, and effectively utilize new and emerging technologies such as the smart grid and energy storage. Energy regulators around the world are struggling to secure reliable electricity supply at affordable price for the consumers. We argued that the conventional variable cost and total cost benchmarking approaches, which ignore the fixed capital or treat it as a variable input, are inadequate tools for meeting these challenges.

In this paper we have provided theoretical, methodological, and operational contributions to address this problem. As our main theoretical contribution, we introduced the concept of conditional yardstick competition. Our approach differs from Shleifer's (1985) original concept in that we draw a clear distinction between the fixed capital and variable cost. The key insight of the conditional yardstick approach is to apply virtual competition only to the variable cost, conditional on the fixed input. Therefore, the conditional yardstick competition does not encourage firms to over-invest, but also does not punish firms for investment that appear as inefficient ex post. If there is a risk of unfair ex post punishment for inefficient investment, then investors will be cautious and require a higher risk premium to compensate for the regulation risk.

As our methodological contribution, we developed a novel nonparametric frontier estimation method in the general multi-input multi-output setting under random noise. We emphasized the importance of shape constraints such as monotonicity, convexity, and constant returns to scale from the perspective of incentives. The proposed estimation method effectively avoids several shortcomings of the conventional frontier estimation methods, including sensitivity of DEA to stochastic noise and the restrictive functional form assumptions of the parametric approaches such as SFA. The proposed method includes several novel features such as the treatment of capital as a fixed input, modeling interruptions as an undesirable output, and the use of the connection points per customer as an exogenous indicator of the operating environment.

The various operational contributions of our study stem from the real-world application of the proposed conditional yardstick approach in the incentive regulation of the Finnish electricity distribution firms in years 2016-2023, which was conducted in collaboration with the Finnish Energy Authority. We discussed the model specification from the point of view of incentives, including the specifications of the variable input, fixed input, desirable outputs, undesirable output, and the operating environment.

Throughout the paper we have emphasized that incentive regulation directly affects the transmission tariffs paid by the customers and the market prices of the regulated grid companies, and indirectly influences competition in the retail markets of electricity and the sustainable energy transition towards renewable energy sources. From the social point of view, electricity grid plays an important role in addressing various challenges posed by such megatrends as climate change, digitalization, and urbanization. These global challenges are well-recognized in Finland, where the renewed energy legislation in 2013 made it mandatory for the distribution companies to install smart meters to all households and strengthen the power grid to sustain extreme weather events. The Finnish government also encourages production of renewable energy by paying feed-in tariffs for wind power, bio-gas, and renewable wood. Since the experiences from deregulation energy sector in many other countries, particularly in the US, have been rather disappointing, we believe the positive experiences of Finland concerning deregulation of the energy market and regulatory reform concerning the power grids should be of broad interest not only in the energy sector, but in other network industries and local monopolies in general.

We conclude by noting that inefficiency loss of the monopoly is not due to public or private ownership, but rather, due to lack of competition. Therefore, forcing local monopolies to compete with their peers in a virtual market place created by the regulator will directly address the root cause of the problem. Indeed, the sample of local monopolies subject to conditional yardstick competition may well include both public and privately owned firms. In the case of a single large public monopoly, conditional yardstick competition could be organized between the regional divisions of the same firm. But if the regulation is effective, predictable and dependable in eliminating monopoly profits without compromising reliability and affordability, we see there no reason for the national or local governments to own assets in such capital-intensive network industries such as electricity distribution. Smarter regulation of the network industries can benefit the investors, the customers, and the society at large. While "gaming the regulator" might yield short-term gains to the regulated firms, a stable, sound, and predictable regulation environment is also in the long-term strategic interest of the owners of the grid companies.

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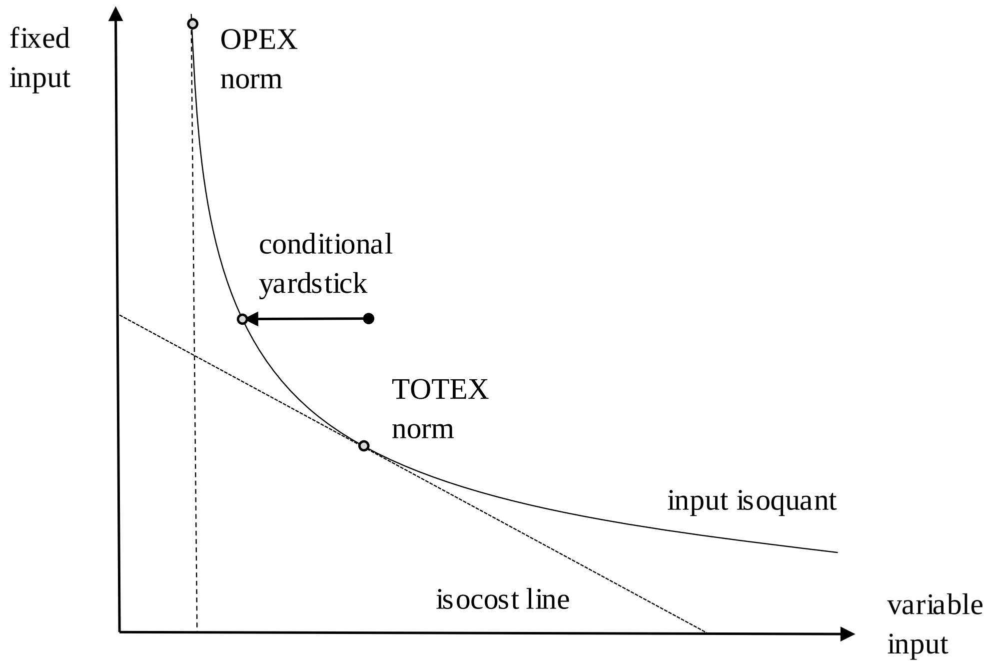

Figure 1: Illustration of the OPEX and TOTEX norms and the conditional yardstick.

Table 1: Average transmission, distribution and service charges (€/MWh) in four Nordic countries in 2014-2019.

	Household consumers (yearly consumption 2.5-5 MWh)				Non-household consumers (yearly consumption 500-2000 MWh)			
	FIN	DEN	SWE	NOR	FIN	DEN	SWE	NOR
2014 Q3-Q4	67.74	68.34	86.94	87.22	27.94	33.94	33.64	35.12
2015 Q1-Q2	72.95	67.48	92.72	88.49	34.05	33.08	36.12	36.39
2015 Q3-Q4	70.15	65.98	100.62	81.81	32.75	34.38	38.92	35.61
2016 Q1-Q2	70.83	65.17	96.60	80.73	30.53	34.27	35.90	33.93
2016 Q3-Q4	66.90	62.49	94.02	82.48	27.30	30.99	31.02	33.38
2017 Q1-Q2	72.65	63.82	94.89	87.26	27.35	31.41	33.49	31.46
2017 Q3-Q4	71.90	59.70	98.10	84.65	26.00	30.40	31.80	31.05
2018 Q1-Q2	65.14	62.67	80.95	86.78	18.84	20.87	25.05	29.08
2018 Q3-Q4	62.84	59.53	78.12	89.70	12.04	13.03	18.22	28.60
2019 Q1-Q2	73.50	67.80	88.13	93.01	20.10	22.90	31.73	29.91

Source: own calculation based on Eurostat and Nord Pool price statistics.