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Capturing heterogeneity in electricity distribution operations: A critical review of latent class modelling

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ABSTRACT

Recently, several articles (Cullmann, 2012; Agrell et al., 2014; Filippini and Orea, 2014; Llorca et al., 2014) address the issue of benchmarking decision making units with different technologies by using latent class models. This method groups units that have similar technology for better comparison. Under this scheme, there are two implicit assumptions: First, that each class reflects a unique technology where its elements are not outliers. Second, classes are assumed to be stationary and fixed. If this assumption is violated, the classification is transient and time-dependent, inadequate for the regulatory use suggested in the seminal papers. We apply latent class models to classify Swedish electricity distributors under different specifications. In most of the models, we identify one large class with approximately 78.4% of the DMU's and two small classes with 7.4% and 14.2% respectively. Moreover, most of small classes elements switch between categories. We contrast our parametric results with nonparametric outlier detector methods and find a relationship between identified outliers and the elements of smaller residual classes. We believe that our work is an important caveat to the adoption of latent class modelling as an alternative or remedy for conventional models, relying on a homogeneous reference set.

1. Introduction

1.1. Background

Energy network regulation is a mission with considerable impact on societal welfare, both in the short and the long run. Regulatory authorities attempt to achieve the dual objectives of assuring a comprehensive, continuous and environmentally compatible service as well as controlling for rent extraction through excessive direct tariffs or by discriminatory pricing of access to impede competitive entry. Defining the business perspectives of the regulated operators, the National Regulatory Authorities (NRA), do not only affect the operations and economic conditions at a given time, but their rulings also signal their commitment for future investments, entry and development by operators. The underlying task is further complicated by the existence of multi-output production (capacity provision, transport work and customer services) and heterogeneous input conditions (specific assets, geographical and systemic constraints, different interfaces) under a steady technological development. The NRA is facing an evident asymmetry of information with respect to the capacity, cost and capabilities of the regulated entities that excludes a naive direct command and control approach to regulation, leaving the room to the traditional economic regulatory approaches; low-powered cost-recovery and high-powered incentive regulation, cf. (Joskow, 2014).

Incentive regulation can be effectively supported by frontier analysis tools, providing good cost norms for distribution operations both statically and dynamically. Frontier analysis can be called the scientific study of best-practice performance in order to empirically determine productivity possibility sets, multi-output production (cost) functions and improvement potentials of firms. Besides the obvious managerial benefits from firm-level information, frontier analysis is put in continuous use by regulatory authorities facing natural monopoly services, such as utilities in water, electricity, natural gas, district heating and telecommunication networks. The concept of *frontier* regulation is natural in these applications as many operators can be expected not only to attempt at obtaining monopoly rents through higher prices, but also through exertion of suboptimal levels of effort.[1] Facing asymmetric information on cost and production functions, the regulator has to employ advanced methods to mitigate the rent extraction opportunities by the firms. Among the methods in actual

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[1] The famous "quiet life" hypothesis by Hicks (1935).

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regulatory use, we find non-parametric methods such as Data Envelopment Analysis (DEA) (Charnes et al., 1978), stochastic frontier analysis (SFA) (Aigner et al., 1977), corrected ordinary least squares regression (COLS), total factor productivity (TFP) models (Coelli et al., 2003), and the stochastic semi-nonparametric method (StoNED) by Kuosmanen (2012). Since the application in regulation is affecting the revenues or (allowable) costs of the firms, the considerations concerning model choice and process are different from retrospective scientific investigations (Agrell and Bogetoft, 2013).

All the methods mentioned rely on the assumption of homogeneity in the services, assets and operations performed by the regulated firms. However, the recent developments of smart grids and massive integration of renewable energy sources at the distribution network level (Agrell et al., 2013) signal increasing difficulties in assuming common delivery and service conditions for operators. Yet, the need for large and timely investments at the grid-level put additional stress at the regulatory regime, in particular its ability to signal a credible level of cost-recovery irrespective of where the operations occur. In the same time, operators increasingly are asked to initiate, participate in and exploit the results from applied research to enable the transition to the low-carbon society in record time. We are therefore at a critical point where the behavioral properties of incentive regulation (focus at value for money by the operators, break from asset-related backward-looking approaches) never have been more important, but the very underpinnings of the methods used are being challenged.

To address this dilemma of heterogeneity a number of *ad hoc* approaches to create homogeneous groups of operators have been proposed and used in regulation. Unfortunately, we will show that many of these attempts do not fulfill reasonable requirements for use in economic regulation. Recently, however, the latent class (LC) models by Lazarsfeld and Henry (1968) have been introduced as promising solutions to the problem for electricity distribution models, see (Cullmann, 2012; Agrell et al., 2014; Filippini and Orea, 2014; Llorca et al., 2014). The concept of an endogenous partition of the reference set ω in independent subsets, called *classes*, each represented by a separate cost function, is seducing and seems like a promising evolution of the state-of-the-art in regulatory benchmarking.[2] Indeed, the numerical applications illustrating the cited works do indicate plausible and interesting classes that may correspond to differentiated production possibility sets.

In this paper we formulate a set of reasonable and necessary conditions for a regulatory cost norm. We then compare the LC models with non-parametric outlier detection methods, an existing and well-established instrument to detect deviations from the homogeneous production technology. The principal difference lies in that LC models identify groups of firms that implement a particular technology whereas the outlier detector methods deals with the inconsistencies or the prominence of a particular observation (Agrell and Niknazar, 2014) without presuming that these salient features are systematic in the sample.

To test our predictions and reserves, we apply the latent-class methodology to a panel of regulatory from data Swedish electricity distribution 2000–2006. The outcome from this application shows a number of interesting findings confirming the violation of some of the necessary conditions stated for regulatory application. In short, although informative the suggested methods are no remedies that replace the fundamental work in defining a stable and robust model specification based on a thoroughly validated and structurally comparable dataset.

Our work makes contributions both to estimation methodology and to regulatory policy. The paper extends earlier work on latent class modeling by highlighting the concept of technology consistency and the relationship to outlier detection techniques. It also provides a structured discussion for the inclusion of such techniques in yardstick regulation that so far has been absent in the literature. From a regulatory policy perspective, the approach and the empirical results, including highlights for the numerical and convergence problems that usually are implicit or omitted, provide solid arguments for adopting a restrictive stance towards data-driven partitioning methods that may jeopardize the legal-economic soundness of the regulatory framework. We believe that this could lead to savings in both time and resources for regulatory authorities, as well as hopefully avoiding regulatory mistakes in rulings and analysis.

1.2. Outline

The outline of the paper is as follows: Section 2 provides a background for the use of frontier cost norms in regulation, the conditions for use and the risks of heterogeneity. Section 3 defines the set of criteria postulated to a regulatory compatible partitioning of the reference set. Section 4 presents the underlying methods for latent class modeling and outlier detection. Section 5 presents the application and data from Swedish electricity distribution operations. The results are presented in Section 6 and the paper is closed with a discussion in Section 7. The full data for the application and the results are published as accompanying material.

2. Frontier-based yardstick regulation

Yardstick regulation has both an intuitive feel and an immediate connection to frontier analysis. The idea behind yardstick regulation (Shleifer, 1985) is to formulate a cost-target $\tilde{c}_i(y|\omega_{-i})$ for an output profile y by firm i by using the [cost] observations of all firms, *excluding* i ω_{-i}. Under the assumption that the observations are correlated and feasible, the target $\tilde{c}_i(y|\omega_{-i})$ is incentive compatible and efficiency-inducing norm. However, Shleifer (1985) did not address the issues of multi-output multi-period production and heterogeneity in the reference set ω. Results by Bogetoft (1997) established that a DEA-based norm is an optimal cost-norm for a multi-dimensional production under a number of assumptions concerning firm behavior and information asymmetry. The optimality of DEA-norms for the inclusion in dynamic regulation regimes[3] was developed in Agrell et al. (2005). The methodology is in current practice in a number of countries in Europe (Haney and Pollitt, 2009). Leaving the details of its derivation to the original works, let us restate a classical yardstick cost norm. The regulator reimburses[4] firm i using a formula that may differ somewhat in notation (see Appendix A for the DEA-based yardstick regulation in Germany since 2007). However, a general formulation takes the following shape for an operator i in a period t beginning with a base year 0:

$$R^i(y_t^i) = [PI_t - X(\omega_0)]V(y_t^i, y_0^i)\{\rho\widetilde{C}(w_0, y_0^i|\omega_0) + (1-\rho)c(w_0, y_0^i)\} + Z_t^i \quad (1)$$

where $c(w, y)$ is the observed actual total expenditure at input prices w and observed output y, $\widetilde{C}(w, y|\omega)$ is the cost norm for input price vector w, output vector y based on a reference set (technology) ω, ρ is the incentive power parameter that determines the part of cost sharing in

[2] An important issue to consider from the practical viewpoint is whether a partition of the reference set based on unobserved heterogeneity is admissible in a court of law as due process. The regulation in place could be challenged due to its discriminatory nature. It could take a substantial effort by the side of the regulator to explain why a company belongs to a certain category based on unobservable heterogeneity. The risk for strategic behavior on behalf of firms mimicking the most "generous" heterogeneity class is also evident. We thank the reviewer for pointing out this strong principal argument against the application of latent class modeling in regulation.

[3] Most actual implementations of yardstick regulation to energy network are in form of periodic revenue-caps with periods from two to four years (Agrell and Bogetoft, 2013).

[4] In practice, the regulator *ex ante* authorizes the transport tariffs to be paid by the captive clients.

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