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Estimating the marginal cost of quality improvements: The case of the UK electricity distribution companies[☆]

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ABSTRACT

The main aim of this paper is to develop an econometric approach to the estimation of marginal costs of improving quality of service. Estimating marginal costs of quality can help energy regulators to design more effective incentive mechanisms for network utilities to achieve optimal quality levels and reduce welfare losses due to sub-optimal quality. We implement this methodology by way of applying it to the case of the UK electricity distribution networks. The proposed method allows us to measure the welfare effect of the observed quality improvements in the UK between 1995 and 2003. Our results suggest that the regulatory incentives to reduce service interruptions have not been strong enough to achieve economically efficient levels of service quality. We, find that the incentives to encourage utilities to reduce network energy losses have led to to performance improvement. We estimate that the observed improvements in quality during the period of the study only represented about 20% of the potential customer welfare gains, hence leaving considerable scope for further economically efficient improvements in service quality.

1. Introduction

Since the 1990s, many regulators of infrastructure industries around the world have implemented incentive-based regulation models that mimic market mechanisms and promote efficiency improvements in natural monopolies. Such schemes have in particular been adopted in the regulation of electricity transmission and distribution networks (Jamasb and Pollitt, 2001). Service quality is an important attribute of electricity distribution for residential, commercial and industrial customers as most functions of the modern economy depend on reliable electricity. The incentive schemes incentivize the network utilities to undertake cost savings. However, the striving for cost savings may result in lower quality of service as maintaining or improving upon a given level of quality is costly (see Ter-Martirosyan, 2003). Concerns regarding the side effects of simple incentive regulation models on service quality have, in recent years, led many electricity regulators to design incentive regulation mechanisms for quality of service in transmission and distribution networks (see Yu et al., 2009a).

Sappington (2005) concludes that there are no simple policy solutions for effective regulation of quality of service but they depend on the information available to the regulator on consumer preferences and production technologies. While previous studies have attempted to quantify the value of service reliability (Allan and Kariuki, 1999; Kariuki and Allan, 1996; Yu et al. 2009a) and have showed that utilities respond to quality of service incentives (Jamasb and Pollitt, 2007; Tangeras, 2009), marginal cost of quality improvements were not explicitly estimated. Basing the incentives on marginal benefit of quality improvement may provide utilities with an overly generous incentive for socially efficient quality improvement.

In some incentive models, as in Norway, quality incentives are integrated in cost benchmarking of the companies for determining their allowed revenues while the UK regulator Ofgem has used quality of service targets with associated penalty/reward schemes for distribution networks. The quality targets can vary across the companies taking into account the heterogeneities among them and their potential to improve during a given distribution price control regulatory period. Meeting the quality targets requires allowances justified in the utilities' periodic capital investment plans to upgrade assets and equipment that need to be approved by the regulator. In designing quality-incorporated regulatory mechanisms, regulators are faced with the task of identifying a demand curve for service quality (i.e. the price that customers are willing to pay for quality) and

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marginal cost of quality improvements. The latter can be viewed as a lower bound for setting incentive targets. Hence, knowledge of the marginal cost of quality improvement and how these compare to marginal benefits or customers' willingness to pay (WTP) for quality can help the regulators in setting better informed quality targets and rewards/ penalties for the companies.

The aim of this paper is to propose a methodology to estimate econometrically marginal costs of improving quality of services in the UK electricity distribution utilities, and assess the effectiveness of the current incentives to improve quality. We also measure the effect on economic welfare of quality improvements in the UK and the welfare losses due to sub-optimal quality.

Section 2 introduces the empirical model and discusses several issues concerning the estimation of the marginal cost of quality of service. Section 3 describes the data and variables used in the empirical exercise. Section 4 presents the parameter estimates using different specifications and estimators. Section 5 summarizes the results, and presents the main conclusions.

2. Specification of the empirical model

In this section we specify an empirical model for estimating marginal costs of improving quality service and apply this to the case of the UK electricity distribution companies.

An important issue to address is that, while accurate information about operational and capital costs and quality of service might be available, the main variable we are interested in, i.e. the marginal cost of quality improvements, is not observed directly. However, this cost may be inferred from previous estimations of the utilities' cost function. This means that while we can estimate 'reasonably well' the cost level for a particular utility, the inferred marginal costs are less accurate — i.e. the confidence intervals and prediction errors are larger than in the cost function.

The *basic* cost function to be estimated can be written as:

$$\ln C = \ln C(y, n, e, q, t) \tag{1}$$

where C is a measure of overall costs of the network utility, y is the amount of energy delivered, n is the network length, e represents network energy losses, and q is a measure of service quality (measured by the length of interruptions, customers minutes lost), and t is a time trend capturing the cost effect of improvements in technology.[1] We include network length to reflect the size of service area. Network length has been used (as an output) by Ofgem and other regulators in benchmarking of the utilities' operating costs. We use energy losses, e, as a cost driver as we are interested in estimating the effect of reducing distribution energy losses on total costs of utilities. An alternative way to write the cost function (1) is:

$$\ln C = \ln C(n, d, e, q, t) \tag{2}$$

where $d = y/n$ is a measure of network density.[2] Functions (1) and (2) are equivalent. However, the interpretation of some coefficients changes, for example, while energy delivered in Eq. (1) is expressed in absolute terms, in Eq. (2) it is expressed in relative terms. The advantage of Eq. (2) is that it becomes easier to measure both economies of scale and economies of density. The first type is related to system expansion at constant density, e.g. urban fringe expansion. As network density is held constant, this type of expansion requires enlarging the current network to meet extra demand. The economies that involve increase in demand and network can be measured by (partial) elasticity of cost with respect to network length, n. The second type involves simultaneously expanding the output and service density, i.e. expansion of service when additional network is not required. These economies can be measured by the (partial) elasticity of cost with respect the network density, d. We expect that the economies in distribution are mostly related to an increase in densities.

We use the sum of operational and capital expenditures as total expenditures (Totex) as the dependent variable because utilities might adopt different strategies to combine operating and capital investment inputs to operate and update their networks and to improve their quality of service (Giannakis et al., 2005).[3]

We include customer minutes lost (CML), i.e. q, as a determinant of the direct private network costs. This allows us to obtain a measure of the marginal costs of quality improvements.[4] The estimated marginal cost of improving quality (which is both a measure of the private and social costs of improving quality) can then be used with any estimate of the social benefit of improving quality (i.e. the social cost of service interruptions) in order to compute welfare losses due to sub-optimal quality levels.[5] Network energy losses and their cost are more closely related to the state of assets and hence expected to be more correlated with Capex than with Opex — as opposed to service quality that can be correlated with both Capex and Opex. Cost of energy losses are easier to measure and are usually based on some annual average of system price.

As in Yu et al. (2009b), we multiply the minutes lost per customer by the number of customers, in order to scale the variable and include it as a cost determinant. Yu et al. (2009b) included the social cost of customer minutes lost as a cost to be minimized together with the direct private costs of the network in a benchmarking exercise. The social benefit of improving quality (as measured by the willingness to pay – WTP – for quality improvement) can change with time, events, or the choice of survey method.[6] The level of CML is a driver of direct private costs for the utilities. The direct private costs are used by

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[1] Customer numbers (cu) and units of energy delivered (y) are the most commonly used outputs in benchmarking of distribution network utilities (Giannakis et al., 2005; Yu et al. 2009a,b). These output variables are important cost drivers and influence the pricing of distribution services. However, the statistical correlation between these two outputs is very large in the present application (over 97%). In order to cope with this collinearity problem we have dropped customer numbers as output. As energy delivered is the product of customer numbers times per capita demand, this does not imply that we ignore cu as it is already included in y. In addition, customer numbers is by far the main driver of change in energy delivered.

[2] Network density is often measured as the ratio of customer numbers to network length. As the correlation between customer numbers and energy delivered is almost 100%, our density measure can be loosely interpreted as the number of customers per network kilometer.

[3] In previous versions of the present paper we also considered Capex and Opex as dependent variables in order to examine the existence of different strategies in the UK utilities to improve quality. In the next sections, due to space limitations, we only present a summary of these results. The details of this analysis can be found in http://www.econ.cam.ac.uk/dae/repec/cam/pdf/cwpe1052.pdf.

[4] Note that customer minutes lost, q, is the "inverse" of a real quality measure. If we call this quality measure as Q, the marginal cost of quality improvements can be computed as:

$$MC = \frac{\partial C(\cdot)}{\partial Q} = \frac{\partial C(\cdot)}{\partial q} \cdot \frac{\partial q}{\partial Q}$$

If the relationship between q and Q can be represented by the linear function $Q = A - q$, where A is the maximum quality level, the above marginal cost reduces to:

$$MC = -\frac{\partial C(\cdot)}{\partial q}$$

In order to obtain a positive marginal cost of quality improvements, the derivative of the cost function with respect to q should be negative. As argued before this might not be the case as q cost might be negatively and positively correlated.

[5] Note that we use a physical measure of service quality instead of 'cost of energy not supplied', which is a function of the length of interruptions and willingness by customers to avoid these interruptions. Its computation, hence, requires using an estimate of customer willingness-to-pay (WTP) for quality improvement, which might be difficult to obtain.

[6] WTP for higher quality or to avoid network interruptions is often obtained from survey based estimates and can be subject to change over time or survey methods. See Yu et al. (2009a) for more details on how WTP can be estimated and the problems of obtaining accurate measurement.