DESIGNING INCENTIVE REGULATION IN THE ELECTRICITY SECTOR[1]

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1. Introduction.

In many industries, competition compels suppliers to serve the best interests of consumers. Intense competition to secure the patronage of consumers can compel suppliers to deliver high-quality services and charge prices that reflect realized production costs, generating only a normal profit for suppliers in the long run.[2] Competition also compels suppliers to continually find new ways to constrain costs (to limit the need to raise prices) and to enhance service quality as industry conditions change, so as to maintain the patronage of existing customers and to attract new customers.

Although competition can thereby enhance consumer welfare in many industries, competition can be prohibitively expensive in industries with massive infrastructure needs and pronounced scale economies.[3] To illustrate, in principle, multiple, ubiquitous transmission and distribution (T&D) electricity networks might be constructed. The networks might then compete to serve customers. However, such competition is only viable in the long run if each network can recover its infrastructure costs and earn a normal return on its investment. Consequently, consumers would have to finance the cost of erecting and operating duplicative T&D networks to secure such competition.[4]

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[2] A normal profit is the minimum profit required to ensure the supplier's continued operation.

[3] Scale economies prevail when the unit cost of production declines as the scale of output increases.

[4] Even if such duplicative costs were not prohibitive, new potential T&D networks might be reluctant to challenge an incumbent network. After financing its infrastructure investment, the incumbent network would find it more profitable to reduce prices to levels that only recover ongoing operating costs than to cease operations. Comparable prices would not allow a new network to recover both network construction costs and network operation costs. The prospect of such unprofitable competition could deter a new T&D network from challenging an incumbent network.

When these duplicative costs are extremely large (as they typically are in the case of electricity T&D network),[5] consumers can be better served by well-designed regulation than by competition. A regulator can authorize the construction and operation of a single T&D network, and then oversee the network's activities. The regulator can protect consumers by limiting the prices that the monopoly network charges for its services, and by specifying the minimum levels of service quality that the network must deliver.

Consumers can be well served by regulation that strives to replicate the discipline that prevails in competitive markets.[6] In principle, a regulator can replicate competitive discipline by directing the T&D network to employ the most efficient production technology,[7] deliver the welfare-maximizing levels of service quality,[8] and set prices that ensure (only) a normal return for the network when it operates efficiently (i.e., at minimum cost). However, such "command and control" regulation will only replicate competitive discipline if the regulator faithfully acts to replicate this discipline and is well-informed about feasible production technologies, the associated efficient production costs, the precise magnitude of a normal profit, and consumer preferences.

In practice, regulators seldom have the information required to ensure that command and control regulation can replicate the discipline of competitive markets. However, regulated suppliers often have better information than regulators about prevailing industry conditions. Therefore, regulators may be better able to replicate competitive discipline and achieve other relevant goals if they can induce regulated suppliers to employ their superior knowledge of industry conditions to achieve the relevant goals. This is the essence of incentive regulation, which can be viewed as the implementation of rules that induce a regulated firm to employ its privileged information to achieve regulatory goals (Sappington, 1994).[9]

The purpose of this chapter is to review the basic principles of incentive regulation and to examine how incentive regulation can be employed to enhance performance in the electricity sector. Section 2 identifies the segments of the electricity sector in which competition is

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5 Fares and King (2017) report that between 1994 and 2014, the transmission, distribution, and administration costs for U.S. investor-owned electric utilities averaged approximately $727 per Customer-Year (in 2015 dollars).

6 Kahn (1970, p. 17) notes that "the single most widely accepted rule for the governance of regulated industries is regulate them in such a way as to produce the same results as would be produced by effective competition, if it were feasible." Baumol and Sidak (1994, p. 5) observe that it is an "almost universally accepted … principle … that the proper role of regulation is [to] substitute for competitive market forces where those forces are weak or absent."

7 The most efficient production technology is the one that enables the network operator to deliver the desired levels of output and service quality at minimum cost.

8 A welfare-maximizing level of service quality is the level that maximizes the difference between the total value (welfare) the quality generates and the total cost of delivering the quality.

9 Incentive regulation is often referred to as "performance-based regulation" in the electricity sector.

prohibitively costly, so incentive regulation is needed to protect consumers. Sections 3 – 5 examine how incentive regulation can be designed to promote the welfare of electricity customers by securing reasonable prices, promoting efficient levels of service quality, and inducing efficient operating costs and capital investment. Section 6 explains how incentive regulation can be designed to encourage the deployment of distributed energy resources like rooftop solar panels and customer- or community-owned storage. Section 7 considers how incentive regulation can help to achieve environmental goals. Section 8 reviews selected empirical studies that examine how incentive regulation has affected the performance of electricity T&D companies in practice. Section 9 provides concluding thoughts, including a discussion of issues that warrant further study.

2. Fostering Competition where it is Cost Effective.

Because it is difficult to replicate the discipline of competitive markets, it can be wise to promote direct competition among suppliers when such competition is not prohibitively costly. This is the rationale behind the restructuring of the electricity industry that has been undertaken in many jurisdictions.[10]

A. Industry restructuring.

Historically, a single vertically integrated provider (VIP) often generated, transported, and delivered electricity to consumers in a given geographic region. For the reasons discussed above, the construction and operation of a single transmission and distribution network avoided large duplicative costs. However, the generation phase of production exhibited substantially smaller scale economies. A single VIP often operated several generation plants that, in principle, could be operated by distinct, independent owners.[11]

In some jurisdictions, VIPs were required to sell some or all their generation assets to foster competition among independent electricity generators. In other jurisdictions, VIPs were required to separate their generation and T&D operations.[12] These divestitures and separations facilitated the development of wholesale markets for electricity, wherein multiple generators compete to supply electricity to large buyers of electricity (e.g., large industrial firms and load serving entities (LSEs) that distribute electricity to retail customers).[13] In principle, sufficiently intense

[10] The ISO/RTO Council (2023) reports that its members "serve two-thirds of electricity consumers in the United States and more than 50 percent of Canada's population" in restructured electricity markets. Borenstein and Bushnell (2015) and Mayer and Trück (2018) further document the extensive industry restructuring in the U.S. and other countries around the world.

[11] See Joskow and Schmalensee (1983) and Joskow (1997), for example.

[12] Divestiture and separation rules, and the fraction of electricity supplied under the various rules, varies considerably across jurisdictions. See Pollitt (2008), Borenstein and Bushnell (2015), Meletiou et al. (2018), and MacKay and Mercadal (2022), for example.

[13] See Glachant et al. (2021, Part I) for detailed discussions of market restructuring around the world.

competition among generators, combined with effective wholesale market design, could eliminate the need for regulation to promote low wholesale prices of electricity and efficient investment in, and operation of, generation assets.

In practice, generators have the potential to exercise market power in many restructured electricity markets (Cicala, 2022; Brown et al., 2023). Consequently, regulations often are imposed to limit the exercise of market power. For instance, if a U.S. generator is determined to have substantial ability to exercise market power, the maximum price it can bid in the wholesale market is capped at an estimate of its marginal cost of supplying the electricity.[14] In addition, the competitiveness of each organized wholesale market in the U.S. is monitored by the relevant ISO's independent market monitoring committee, and by referrals and complaints to the Federal Energy Regulatory Commission (FERC). The FERC disciplines generators that engage in anticompetitive behavior (FERC,2022).

Regulators also act to increase the number of independent generators that operate in wholesale markets. They do so, for example, by mandating virtual asset divestitures. Such a divestiture is effectively a long-term lease on a generation unit. The lessee, often a new entrant, determines how much electricity to bid into wholesale markets and the associated offer terms, while the lessor operates the unit.[15] Some regulators also require load serving entities to procure electricity from generators via long-term contracts.[16] Long-term contracts can help to limit the risk and uncertainty that generators face when they compete to supply electricity in wholesale markets. Reduced risk and uncertainty can encourage expanded operation by generators, especially new, small generators.

Thus, while restructuring created competitive wholesale markets, it did not end all regulation of these markets. In the U.S., an ISO (or Regional Transmission Organization) proposes rules to govern relevant market operations, typically with input from numerous stakeholders and an independent market monitoring committee. The FERC reviews the proposed rules and specifies the final rules that govern market operations.[17] The national regulator – the Office of Gas and Electricity Markets (Ofgem) – also oversees market operations (and sets performance standards, pricing policies, and reward structures for T&D suppliers) in the U.K. In contrast to the U.S. and U.K., electricity markets are primarily regulated at the provincial level in Canada.[18]

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[14] See Graf et al. (2021) and Adelowo and Boland (2022), for example.

[15] Virtual divestitures have been implemented in Alberta, Belgium, the Netherlands, Denmark, Spain, Portugal, France, Germany, and the UK. See Brown et al. (2023), for example.

[16] Australian Government (2019). A load serving entity is an entity that provides or sells electricity to end users (e.g., a distribution utility).

[17] See Paulos (2021) for details.

[18] The Canada Energy Regulator regulates electricity exports to the U.S. and inter-provincial transmission interties (Pineau, 2021).

B. Competition for the market.

Although direct competition among T&D companies is prohibitively costly, it is conceivable that potential competition might be employed to motivate an incumbent T&D company to operate efficiently and to limit its charges to levels that produce only a normal profit. Specifically, potential operators of the T&D network might periodically be permitted to specify the rates they would charge for their services if they were to replace the incumbent T&D operator in whole or in part.[19] In principle, such competition for the right to provide T&D services could conceivably replicate the discipline that would arise in the presence of direct competition among T&D companies.[20]

In practice, there are at least four reasons why such "competition for the market" alone may not be an effective substitute for actual competition in the market.[21] First, the set of well-informed potential T&D suppliers might be limited, in part because such operations can be complex and require substantial expertise and detailed knowledge of local operating conditions. When few potential operators compete for the right to serve as the actual T&D operator, the competition may not be particularly intense, so the selected operator may secure substantial extranormal profit. Second, it can be difficult to predict accurately all relevant operating conditions that will ultimately prevail. Consequently, even the best-informed potential T&D operators may find it challenging to determine the prices they would need to charge to secure a normal profit.

Third, it can be challenging to specify in advance all relevant elements of a T&D company's performance. Furthermore, it can be costly to monitor all relevant dimensions of the company's performance, and to enforce the terms of any performance contract.[22] Fourth, the prospect of losing the right to serve as the T&D operator might discourage the incumbent T&D company from undertaking efficient levels of network investment.[23] For all these reasons, competition for the market alone typically cannot control the activities of a monopoly supplier of T&D services effectively.[24]

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19 Alternatively, or in addition, the potential operators might specify the formulas they would employ to set rates for their services over time, as demand and costs change.

20 See Demsetz (1968) and Williamson (1976), for example.

21 In France, municipalities typically own the electricity distribution infrastructure and contract with another entity to manage and operate the network. However, this entity typically is Enedis, a subsidiary of the state-owned enterprise Electricité de France. La Commission de Régulation de l'Énergie, the national energy regulator, oversees the operations of the distribution (and transmission) system operators in France. For additional details, see Wainer et al. (2022) and https://www.cre.fr/en/Electricity/Electricity-networks/electricity-networks.

22 See Crocker and Masten (1996), for example.

23 See Laffont and Tirole (1998), for example.

24 Some jurisdictions, including the city of Chicago, have seriously considered the replacement of the incumbent T&D company. Although incumbent suppliers have been replaced historically (Kwoka,

C. Yardstick regulation.

"Yardstick" (or "benchmark") regulation can sometimes be employed to mimic the discipline of direct competition. Under yardstick regulation, the authorized revenue for a T&D company in one geographic region reflects the costs achieved by T&D companies that operate in other geographic regions. When a regulated firm's authorized revenue is based more on the costs of other firms and less on its own realized cost, the firm's incentive to reduce its own cost is enhanced. When multiple regulated firms face similar operating conditions, setting each firm's revenue to reflect the costs achieved by the other firms can induce all firms to minimize their costs while eliminating the extranormal profit of each firm.[25]

In practice, the minimum cost that one T&D company can achieve often differs from the minimum cost that another T&D company can achieve. It is important to account for exogenous differences in efficient costs when employing yardstick regulation. Otherwise, firms with unavoidably high costs may not be afforded the opportunity to earn a normal profit. Furthermore, firms with relatively low efficient costs may secure substantial extranormal profit.

Accounting for exogenous differences in efficient costs can be challenging. It is difficult to identify all factors that affect costs and to determine the precise impact that each factor has on efficient costs.[26] However, sophisticated econometric techniques have been developed that employ data on the performance of multiple T&D companies and the conditions under which they operate to estimate the costs that individual companies can reasonably achieve.[27] Consequently, when the required data are available, yardstick regulation has the potential to mimic the discipline of competitive markets by setting a T&D company's allowed revenue to reflect its estimated efficient cost, which in turn reflects the costs achieved by other T&D companies, after accounting for relevant differences in industry conditions (e.g., differences in input prices, infrastructure characteristics, terrain characteristics, climate, and customer density).

D. Summary.

In summary, many VIPs have been required either to divest some or all their generation assets or to separate their generation and T&D operations. These divestitures and separations have helped to increase direct competition among generators. Direct competition among T&D companies typically is absent, and competition for the right to serve as the sole supplier of T&D services is rare. Yardstick regulation of T&D companies is more common. It can help to mimic

1996, chapter 7), and some continue to be replaced on occasion (American Public Power Association, 2016; European Commission, 2018), such replacement has been rare in recent years (Gheorghiu, 2020).

[25] See Shleifer (1985), for example.

[26] See Pollitt (2005), and Haney and Pollitt (2013), for example.

[27] See Jamasb and Pollitt (2000, 2003) and de Mendonça (2023), for example.

competitive discipline when regulators have access to the data required to reliably control for relevant differences in the operating conditions of regulated T&D companies.

3. Employing Incentive Regulation to Secure Low Prices for Consumers.

Now we consider how regulators can employ incentive regulation of T&D companies to pursue regulatory goals when the companies have better information about relevant industry conditions than does the regulator.[28] We assume that the regulator seeks to maximize the welfare of final consumers of the electricity that T&D networks transport and deliver.[29] To maximize this welfare, the regulator will attempt to secure low prices and high levels of service quality for consumers while ensuring the regulated T&D company has a reasonable opportunity to secure at least a normal profit. The regulated firm must be afforded such an opportunity so it can attract the capital needed to finance the investment required to deliver high-quality services to customers.

A. Complications introduced by limited information and limited instruments.

As noted above, a regulator's attempt to maximize consumer welfare is complicated by limited knowledge of the most efficient production technology for the T&D company, the minimum operating cost the prevailing technology enables, and the exact level of earnings that ensures a normal profit for the T&D company. Regulators typically also have limited knowledge of the precise value that consumers place on increased levels of service quality.[30]

This limited information complicates a regulator's task of replicating competitive discipline at any moment in time. Dynamic considerations render the task even more challenging. Innovation that lowers production costs and enhances product quality is a driving force in many competitive markets. Industry suppliers pursue innovation to increase their short-term profit, recognizing that competition will dissipate extranormal profit in the long run. To induce innovation, regulators typically must offer the prospect of enhanced profit, at least for a limited

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[28] The same principles that underlie the design of incentive regulation for T&D companies underlie the design of incentive regulation for generation companies in settings where these companies do not face substantial competition from other generation companies.

[29] This focus abstracts from the possibility that regulators might be "captured" by (and so promote the interests of) the firms they regulate (Stigler, 1971; Dal Bo, 2006). We equate consumer welfare with consumer surplus, which is the difference between the value that consumers derive from a service and the amount they pay for the service. For simplicity, much of the ensuing discussion also abstracts from the possibility that the regulator might explicitly favor some consumer groups over others (e.g., Posner, 1971).

[30] Regulators can improve their information about prevailing industry conditions by requiring the firms they regulate to report relevant performance information (about demand, costs, and service quality, for example) and by comparing the reported data to corresponding data from other jurisdictions.

period of time.[31] However, regulators face constant pressure to secure low prices for consumers. Such pressure can make it difficult for regulators to allow firms to earn extra-normal profit for an extended period of time.[32] Consequently, it can be challenging for regulators to induce regulated suppliers to undertake innovation that reduces costs and enhances service quality.

A regulator's task is also complicated by the limited set of policy instruments at her disposal. In particular, the maximum financial penalty a regulator can credibly threaten to impose on a T&D company typically is limited. A penalty that reduces the company's expected profit below a normal profit (i.e., a penalty that violates the company's "break-even constraint") can induce the company to underinvest in new capital or even cease operations in the long run. Such an outcome would impose substantial harm on consumers (and would likely end a regulator's tenure).

The financial reward a regulator can credibly promise to deliver to a T&D company also is limited in practice. Consumers, designated consumer advocates, and politicians will object strenuously if a regulated T&D company earns enormous extranormal profit, regardless of the cause of the profit. These objections often compel a regulator to limit the company's profit to what is deemed to be a reasonable level by reducing the prices the company charges for its services.

B. Tailoring policy to prevailing information and instruments.

The best way for a regulator to maximize consumer welfare varies with the nature of her information and her policy instruments. To illustrate this conclusion, first consider a hypothetical setting in which the regulator has limited knowledge of relevant industry conditions, but knows that the T&D company always works diligently to maximize the welfare of consumers. In such a setting, the regulator can allow the company to employ its superior knowledge of industry conditions to choose the most efficient production technology and the welfare-maximizing levels of service quality, and work diligently to deliver the chosen levels of quality at minimum cost. The regulator can set prices to reflect realized costs, thereby ensuring that the company earns (only) a normal profit. Such "cost of service regulation" (COSR) will serve customers well in this hypothetical setting where the regulated T&D company shares the regulator's goal and works diligently to achieve the goal.

In practice, privately-owned (profit-maximizing) companies must pursue the interests of their shareholders. Even executives in publicly-owned T&D companies may not act solely to maximize consumer welfare. These executives may seek to further their personal welfare, the

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[31] Weisman and Pfeifenberger (2003) explain how financial incentives for improved performance induce regulated firms to discover new and superior ways to enhance consumer welfare.

[32] Such pressure, coupled with the fact that many investment costs in the electricity sector are sunk costs, can even make it challenging for regulators to avoid profit below normal levels.

welfare of company employees, or the objectives of local politicians, for example. Consequently, the hypothetical setting in which COSR maximizes consumer welfare seldom prevails in practice.

Even when a regulated enterprise acts to maximize its profit rather than consumer welfare, a regulator may be able to induce the enterprise to minimize its operating costs. In principle, the regulator can do so by awarding the firm the full amount of any cost reduction it achieves. However, such a reward structure may provide little benefit to consumers unless the regulator manages to capture for consumers a portion of the benefits associated with realized cost reductions.

Price cap regulation (PCR) attempts to motivate a regulated enterprise to work diligently to reduce its operating costs, and to secure for consumers a substantial fraction of the anticipated cost reduction. PCR does so by requiring the firm to initially set prices below the levels that would prevail under COSR. To illustrate, the prices might be set under PCR to reflect an estimate of the prices that would prevail in the presence of industry competition. In return for delivering this initial benefit to consumers, the firm's prices are not ratcheted downward to match realized cost reductions during the term of the price cap plan.[33] Severing the link between authorized prices and realized costs enhances the regulated firm's incentive to reduce its costs.

Alternatives to PCR can be advisable when the regulator's knowledge of the prices that would prevail in the presence of intense industry competition is limited. Earnings sharing regulation (ESR) is one such alternative.[34] ESR operates much like PCR except that the regulated firm is required to share with its customers a fraction of its realized earnings above, and perhaps below, specified thresholds. This sharing helps to ensure that the regulated firm only secures substantial extranormal profit if consumers simultaneously receive substantial benefits. These benefits might take the form of price reductions that reduce the firm's profit by the stipulated level of earnings sharing, for example. The sharing can also help to ensure that the firm's break-even constraint is respected by increasing prices (to reflect the stipulated level of earnings sharing) when realized earnings fall below any minimum level of profit that is established.

Although ESR helps to avoid the exceptionally high or low earnings that PCR can admit when the regulator's knowledge of industry conditions is limited, ESR provides less incentive for cost reduction than does PCR. When the firm is not awarded the full amount of any particularly

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33 Instead, the firm's prices typically are permitted to increase over time at a rate that reflects the difference between an inflation index (an "*I* factor") and a measure of anticipated productivity gains (an "*X* factor"). If the *I* factor approximates the rate at which the firm's input prices rise, then the X factor typically approximates the rate at which the firm's productivity is expected to rise if the firm operates efficiently. If the *I* factor reflects a general rate of price inflation (e.g., the consumer price index or the gross domestic price index), then the *X* factor typically is designed to reflect the extent to which the regulated industry is deemed capable of achieving more rapid productivity growth than other sectors of the economy. See Bernstein and Sappington (1999, 2000) for details. The appropriate length of a price cap plan is considered in Section 3.D below.

34 See Schmalensee (1989), Lyon (1996), and Hawdon et al. (2007), for example.

large cost reductions it achieves, the firm's incentive to secure such cost reductions is diminished. Consequently, realized cost reductions (and consumer welfare) may be lower under ESR than under PCR.

In summary, PCR can be an advisable form of incentive regulation when: (i) the potential for cost reduction is known to be large; (ii) the regulator can predict reasonably accurately the amount of cost reduction the regulated firm can achieve when it is strongly motivated to do so; and (iii) the regulator can credibly promise to permit unusually high and unusually low levels of profit. In contrast, ESR may be preferable when the regulator: (i) has less accurate information about the potential for cost reduction; and (ii) cannot credibly promise to permit exceptionally high or exceptionally low levels of profit.

C. Menus of plan options.

A regulator need not limit herself to dictating a single regulatory plan, e.g., either PCR or ESR. Sometimes, a regulator can secure a higher level of expected consumer welfare by allowing the regulated firm to choose its preferred plan from a carefully-designed menu of plan options. This is the case because when the regulator imposes a single regulatory plan, she relies solely upon her own limited information to do so. In contrast, when the regulator allows the firm to choose one plan from a menu of plan options, the regulator may be able to induce the firm to employ its superior knowledge of industry conditions to implement the plan that is best for consumers.

To illustrate this more general principle,[35] first suppose the regulator limits herself to implementing a single PCR plan. To ensure the firm's break-even constraint is respected, the regulator may mandate only a modest initial price reduction in this setting. Now suppose that the regulator allows the firm to choose its preferred plan from a menu of plan options. For simplicity, suppose the menu consists of a PCR plan and COSR. The presence of this menu ensures the regulated firm always has the option to choose a plan (i.e., COSR) that respects its break-even constraint. Consequently, when the regulator designs the PCR plan to include in the menu of plan options, she can be less concerned that the PCR plan might not satisfy the firm's break-even constraint. Therefore, the regulator can mandate a more substantial initial price reduction in the PCR plan.

In essence, by presenting the firm with the option to choose COSR, the regulator secures insurance against violating the firm's break-even constraint under PCR. The firm will choose the PCR plan if and only if it is confident that it can secure at least a normal profit under the plan. This insurance can embolden the regulator to implement a PCR plan that, when selected by the firm, secures a higher level of consumer welfare than does the plan the regulator implements in the absence of insurance.

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[35] For more general analyses of the optimal design of menus of regulatory plans, see Laffont and Tirole (1986, 1993), Armstrong and Sappington (2004, 2007), and Joskow (2007), for example.

Despite their considerable merit, explicit menus of plan options are not common in practice. This may be the case in part because such menus are more complicated to design than a single plan.[36] In addition, regulators may fear being viewed as weak, indecisive, or subservient to the regulated firm if they allow the firm to choose the plan that is ultimately implemented. However, menus of plan options have been employed in the electricity sector, as we explain further below.[37]

D. Plan duration and re-openers.

The length of an incentive regulation plan matters, as do the details of the successor regulatory plan. The longer is the initial incentive regulation plan and the less the successor plan ratchets prices downward to reflect realized cost reductions, the stronger are the incentives in the original plan to reduce operating costs during the initial plan.[38] However, this benefit of a relatively long plan and limited ratcheting comes at a cost. A long plan and limited ratcheting can delay and reduce the sharing of realized efficiency gains with consumers. A relatively long incentive regulation plan (e.g., five or more years) can be advisable when the potential for cost reduction is pronounced and the regulator can predict the magnitude of the reduction relatively accurately. Shorter plans (and perhaps ESR rather than PCR) can be appropriate when the regulator has limited ability to assess the magnitudes of potential cost reductions. In such a case, a shorter plan allows the regulator to modify plan parameters before industry outcomes (e.g., the firm's earnings) diverge too far from anticipated levels.

Relatively long plans that entail credible promises can be particularly effective at inducing long-lived investment. Investment in network modernization or expansion typically entails large up-front costs that generate benefits in subsequent years. To avoid "rate shock," regulators generally do not increase prices immediately to cover the full cost of the investment as it is being

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[36] Furthermore, the increment in expected consumer welfare that a regulator can secure by employing a menu of plan options rather than a single plan can sometimes be limited. See Reichelstein (1992), Bower (1993), McAfee (2002), Rogerson (2003), Chu and Sappington (2007), and Brown and Sappington (2019), for example.

[37] Sappington and Weisman (1996, chapter 6) describe a menu of plan options that has been employed in the U.S. telecommunications sector. In some settings, the terms of the prevailing regulatory plan are determined by negotiations between the regulated firm and intervenors such as consumer advocates (Littlechild, 2009). In such settings, the regulated firm might be viewed as choosing between an incentive regulation plan favored by intervenors and COSR (because the firm typically has the right to request a formal cost-of-service rate case).

[38] The Alberta Utilities Commission (AUC) has employed an efficiency carry-over mechanism (ECM) to help enhance a utility's incentive to realize efficiency gains, particularly toward the end of an incentive regulation plan. The ECM: (i) calculates the difference between the utility's actual rate of return (ROR) during the plan and its authorized ROR; and (ii) allows the utility to retain one-half of this difference (up to a maximum of 0.5%) during the two years following the end of the plan (AUC, 2012, §9).

undertaken. Instead, the regulator promises to set future prices above prevailing operating costs to finance the earlier investment.

Once the investment is completed, the firm's forward-looking break-even constraint will not be violated if prices are reduced to the level of prevailing operating costs. Consequently, regulators may face pressure to reduce the higher prices they promised to finance earlier investment. A relatively long incentive regulation plan with a credible, well-specified trajectory of permissible prices can help to limit such "regulatory hold-up." Limiting such hold-up is a crucial element of ensuring that a regulated firm will undertake vital network investment on an ongoing basis.

In practice, incentive regulation plans in the electricity sector are often implemented for four or five years.[39] Plans of this duration can admit considerable potential for major, unanticipated changes in industry demand or costs. Consequently, the plans typically include "re-opener" provisions that specify in advance the conditions under which modifications of the prevailing plan will be considered. Modifications usually will be considered only if an exogenous, unanticipated change in industry conditions arises that has a substantial impact on the earnings of the regulated firm and that is not reflected in plan parameters.[40] For instance, the government might unexpectedly mandate substantial, immediate improvements in network security in response to a heightened risk of an attack by terrorists.

The relevant change in industry conditions must be exogenous, i.e., beyond the control of the regulated firm. Otherwise, the firm might request additional compensation to offset the deleterious consequences of inappropriate managerial decisions. Alternatively, the regulator might attempt to capture for consumers the benefits of unexpectedly large cost reductions that arise due to exceptional managerial performance.

The relevant change in industry conditions must also be unanticipated. The financial implications of anticipated changes (e.g., predictable changes in input prices or patterns of customer demand) should already be reflected in plan parameters (e.g., the initial price reductions that must be implemented at the start of the prevailing PCR plan).

In addition, the change in industry conditions must have substantial financial implications.

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[39] Ofgem's RIIO ("Revenue = Incentives + Innovation + Outputs") incentive regulation plan, which was implemented for distribution utilities in the UK in 2015, scheduled a formal review after eight years of plan operation (Mandel, 2014). The sequel plan schedules a review after five years (Ofgem, 2023; Thomas, 2023). Lowry et al. (2017, p. 2.1) observe that rate hearings associated with incentive regulation plans in the electricity sector "are typically held every four or five years."

[40] The AUC specifies five criteria the change must satisfy to warrant consideration. (1) The impact must be attributable to some event outside management's control. (2) The impact of the event must … have a significant influence on the operation of the company … (3) The impact of the event should not have a significant influence on [plan parameters, such as the rate at which the firm's prices can increase annually]. (4) All costs claimed as an exogenous adjustment must be prudently incurred. (5) The impact of the event was unforeseen (AUC, 2012, ¶524).

For example, only exogenous, unanticipated changes that increase or reduce the regulated firm's revenue or cost by more than two percent might be considered. Such a restriction can prevent an excessive number of resource-intensive regulatory hearings to determine whether the terms of the prevailing incentive regulation plan should be modified.[41]

E. Rate structure.

By enhancing incentives for innovation and cost reduction, incentive regulation allows regulated T&D companies to charge lower prices while securing at least a normal profit. Incentive regulation can also specify how realized price reductions are structured.

In many jurisdictions, per-unit T&D charges are lower for large commercial and industrial (C&I) customers than for residential customers.[42] The relatively low rates for large C&I customers are designed in part to discourage large purchasers of T&D services from seeking alternative suppliers of these services (or employing alternative energy supplies).[43] Rates for large C&I customers that ensure their continued patronage while generating revenue that exceeds the incremental cost of serving these customers allow T&D companies to profitably set lower rates for residential customers than they otherwise could.

To further ensure that residential customers can afford electricity T&D services, regulators often dictate relatively low rates or rate discounts for low-income residential customers.[44] Income-adjusted rates can be a particularly important vehicle for ensuring the affordability of T&D rates that reflect the costs of serving customers. Most costs of supplying T&D services are fixed costs that do not vary with the amount of electricity supplied. Consequently, volume-based pricing of T&D services can inefficiently discourage electricity consumption.[45] However, a uniform T&D charge that reflects the average (largely fixed) cost of supplying T&D services can entail a large increase in the T&D bill that small residential customers face. Therefore, when regulators implement T&D charges that are less sensitive to the volume of electricity supplied, they often favor discounted (fixed) charges for low-income residential customers.[46]

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[41] The AUC defines "substantial" to entail at least a 40 basis point change in the firm's return on equity (AUC, 2012, ¶535).

[42] See U.S. Energy Information Administration (2023), for example.

[43] See Su (2015), for example.

[44] See California Public Utilities Commission (2023), for example.

[45] Reduced electricity consumption can reduce carbon emissions, depending upon the technology employed to generate electricity. However, it can also induce increased consumption of other energy sources (e.g., natural gas), thereby potentially increasing carbon emissions. See Borenstein and Bushnell (2022), for example.

[46] Such income-adjusted fixed T&D charges are presently under consideration in California (California Public Advocates Office, 2023).

F. Summary.

In summary, any incentive regulation plan that is implemented should be tailored to the regulator's information and policy instruments. Although a PCR plan might provide stronger incentives for cost reduction, an ESR may better promote consumer welfare if the regulator has particularly limited knowledge of relevant industry conditions and cannot credibly promise to permit exceptionally high or low levels of profit. Menus of plan options can sometimes be employed to induce the regulated firm to employ its superior knowledge of industry conditions to choose the regulatory plan that maximizes consumer welfare. Re-openers can be employed to modify the prevailing regulatory plan if major, unanticipated, exogenous changes in industry conditions arise. Mandated price structures are often employed to promote regulatory goals such as ensuring affordable service for low-income customers.

4. Employing Incentive Regulation to Secure Efficient Levels of Service Quality.

In addition to promoting cost reductions that admit lower prices, incentive regulation can be designed to motivate a regulated enterprise to deliver efficient levels of service quality.[47] The efficient level of a particular dimension of service quality (e.g., system reliability)[48] is the level that maximizes the difference between the benefits generated by the quality and the costs of delivering the quality. If the regulator had accurate information about these benefits and costs, she could simply require the firm to deliver the efficient level of quality in return for a payment that reflects the corresponding costs.

In practice, a regulator seldom has the information required to precisely identify efficient levels of service quality in the jurisdiction she oversees. However, yardstick comparisons can provide useful information about the levels of service quality that other regulated firms deliver, the associated costs, and perhaps customer assessments of the service quality they receive.[49] This information can help a regulator to determine efficient levels of service quality in the jurisdiction she oversees, although the determination is likely to be imperfect even when extensive, reliable yardstick data are available. This is the case because many factors affect efficient levels of service quality. For example, a given level of system reliability can be relatively costly to ensure in regions where electricity is generated by intermittent resources, where electricity demand varies more

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[47] Because incentive regulation can provide strong incentives for cost containment, it can motivate a regulated enterprise to reduce the level of service quality it delivers. Consequently, it typically is advisable to specify explicit service quality standards and associated financial penalties for sub-standard levels of quality in incentive regulation plans. See Sappington (2005), Ter-Martirosyan and Kwoka (2010), and Ajayi et al. (2022), for example.

[48] SAIDI (a system average interruption duration index) and SAIFI (a system average interruption frequency index) often are employed to measure system reliability.

[49] See Giannakis et al. (2005), Yu et al. (2009a,b), and Jasamb et al. (2012), for example.

widely, where the grid infrastructure is older, where relatively little of the transmission and distribution cable is buried, and where vegetation grows rapidly around aerial cable.

Even when a regulator has limited knowledge of the cost of providing service quality, she may be able to induce the regulated firm to supply the efficient level of service quality if the firm is well informed about this cost. In such a setting, the regulator can specify: (i) a quality standard; (ii) the financial penalty the firm will incur as realized quality declines below the standard; and (iii) the financial reward the firm will receive as realized quality increases above the standard. The penalties and rewards can be set to reflect the corresponding losses and gains consumers experience as quality declines below or increases above the standard.

When it faces such penalties and rewards, the firm will maximize its profit by: (i) increasing quality whenever the corresponding benefit to consumers (which is also the financial reward the firm receives) exceeds the associated cost; and (ii) reducing quality whenever the corresponding cost savings exceed the associated reduction in consumer benefits. Consequently, this reward and penalty structure will induce the firm to employ its superior knowledge of the cost of enhancing quality to deliver the efficient level of quality.

A reward structure of this type can deliver considerable rent to the regulated firm if the initial quality standard is set well below the efficient level of service quality (so the firm receives compensation well above the associated cost of increasing quality to the efficient level). However, this rent can be reduced over time if rewards for enhanced service quality are promised for a limited period of time, just as financial rewards for cost reduction are provided for a limited time period (i.e., until the end of the prevailing regulatory plan) under price cap regulation.

In practice, limited knowledge of consumer preferences typically precludes regulators from inducing efficient levels of service quality. However, regulators employ their limited information to set what they deem to be appropriate performance standards, and impose penalties for failure to achieve the specified standards. Penalties for sub-standard system reliability are a case in point. Regulators often establish a target level of system reliability that reflects historic performance, and impose financial penalties on a utility if its performance is significantly below the target level of reliability. To illustrate, in Hawaii, the regulated utility faces no penalty if its realized network reliability is within one standard deviation of the identified historic reliability level. Lower levels of realized network reliability trigger financial penalties, up to 20 basis points if the realized performance is more than two standard deviations below the identified historic standard.[50]

In recent years, regulators have become increasingly concerned with grid resiliency, as

[50] See Prause (2021) for additional details of Hawaii's policy. Ofgem's RIIO plan for distribution utilities in the UK includes more pronounced penalties (and rewards) – up to 250 basis points – for network reliability performance that lags (or exceeds) performance targets (Whited et al., 2015). See Prause (2021) and Whited et al. (2015) for discussions of additional service quality incentive programs that have been implemented in practice.

well as grid reliability. Grid resiliency pertains to network performance during relatively rare, but extreme, events that can cause large-scale network outages. These events include particularly severe weather (e.g., hurricanes or floods), wildfires, cyber or physical terrorist attacks, and earthquakes. Investments to promote network resiliency include burying distribution cables underground, reinforcing poles that support overground wires, expanding distributed generation and microgrid operation,[51] and enhancing physical and cyber security (Berkeley Lab, 2019). In principle, a regulator might attempt to induce a utility to undertake the efficient level of resiliency investment by imposing the full costs of a widespread network failure on the utility. However, such large penalties typically are not feasible (due to bankruptcy laws, for example).[52] Consequently, in practice, regulators often mandate specific investments to enhance network resiliency and compensate the utility for its associated investment costs.

5. Employing Incentive Regulation to Promote Efficient Capital Investment.

Transmission and distribution networks require substantial ongoing investment. Consequently, it is important to structure regulatory policy to ensure that efficient levels of investment are undertaken on an ongoing basis.[53]

To ensure the continued supply of vital investment, regulators can be inclined to promise returns on investment that exceed the minimum return required to meet the firm's break-even constraint (Werner and Jarvis, 2022). When it anticipates such a return, a regulated enterprise can be tempted to exaggerate the efficient level of capital investment. Regulators can employ a menu of regulatory options to help limit such exaggeration, as the Office of Gas and Electricity Markets (Ofgem) has done in the UK. Under Ofgem's policy (Ofgem, 2004), a T&D company can choose its preferred level of capital investment from a set of possible investment levels, one of which is the level recommended by an outside consultant. The higher is the level of investment chosen by the company: (i) the lower is the rate of return on investment the company is awarded; and (ii) the smaller is the fraction of achieved cost efficiencies the company is permitted to retain.[54] The

[51] Distributed generation refers to the generation of electricity at multiple (distributed) sites rather than at a single centralized location. (See Section 6 below.) A microgrid refers to a relatively small network of electricity users who can secure electricity from a local source (if only for a relatively short duration) when their access to the central grid is interrupted.

[52] To illustrate, in January 2019, Pacific Gas and Electric Company filed for bankruptcy protection in light of the billions of dollars in potential liabilities it faced because its activities were believed to have contributed to massive wildfires in California (Roth, 2020).

[53] The efficient level of investment is the level that maximizes the difference between the benefits derived from the investment and the cost of the investment.

[54] See Crouch (2006), Cossent and Gomez (2013), and Joskow (2008, 2014) for more detailed descriptions and assessments of this policy. Achieved cost efficiencies are the difference between the operating costs the T&D company is expected to incur when it operates efficiently and the costs the company actually incurs.

compensation schedule is designed to ensure that T&D companies with pronounced ability to operate efficiently with limited additional capital investment will undertake relatively little capital investment, whereas companies with more limited such ability will find it most profitable to undertake higher levels of investment.[55]

The efficient level of investment varies with the maximum demand for electricity. Policies that reduce this maximum demand – including demand response policies – can reduce the efficient level of investment. Under incentive-based demand response programs, an electricity customer can agree in advance (in return for specified compensation) to restrict his electricity consumption when the potential for excess demand arises.[56] Under direct load control programs, the electricity supplier is authorized to turn off the customer's equipment (e.g., an air conditioning unit or hot water heater) during periods of unusually high demand for electricity. Under curtailable load programs, the customer is required to reduce his electricity consumption to pre-specified levels (by setting his thermostat at a designated level, for example).[57]

Voluntary programs of this type can enhance the welfare of program participants and non-participants alike. Well-informed participants benefit because they receive compensation that exceeds the inconvenience they suffer when their electricity is curtailed. (Otherwise, they would not enroll in the program.) Non-participants also benefit when payments to participants are less than the costs of expanding system capacity to a level that avoids excess demand. Thus, much like incentive regulation plans that provide financial incentives to regulated firms, programs that provide financial incentives to some consumers can enhance the welfare of all consumers.

6. Employing Incentive Regulation to Promote Distributed Energy Resources.

Historically, electricity has been generated at relatively few centralized locations and delivered to many dispersed customer locations. Today, distributed energy resource technologies (DERs) are disrupting this traditional paradigm by permitting the generation and/or management of electricity in the distribution system, closer to where it is consumed. DERs include remote generation of electricity (e.g., rooftop solar generation) and electricity storage. Individual DERs or combinations of DERs that permit reductions in traditional capital investments are often referred to as non-wire alternatives (NWAs). NWAs can include the management of electricity

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55 Regulatory policies that provide incentives for reduced infrastructure investment can help motivate T&D companies to (efficiently) extend the life of capital assets beyond the time at which they are routinely replaced under COSR.

56 Under price-based demand response programs, surcharges on electricity consumption are imposed during periods when excess demand might otherwise arise. See Albadi and El-Saadany (2008) for a discussion of the types, benefits, and costs of demand response programs.

57 The customer is penalized if he does not comply with his original promise.

consumption, including programs that reward customers for curtailing their electricity consumption during periods where the demand for electricity approaches network capacity.[58]

Although DERs can sometimes permit a reduction in total network infrastructure investment, they do not necessarily do so. Additional investment may be required to support new patterns of electricity flows caused by DERs, particularly when these flows peak at different times than traditional electricity flows peak.[59]

The prevailing regulatory policy can affect a firm's incentive to implement DERs and NWAs. If the prevailing regulatory plan does not link the firm's authorized revenue to its realized cost or to the specific inputs the firm employs to serve customers, then the firm will be motivated to minimize its cost by implementing a DER if and only if the DER is expected to reduce the firm's total cost of serving its customers. In contrast, if the prevailing regulatory plan provides more revenue to the firm when it employs a more capital-intensive production technology, then the firm will be inclined to favor a DER that expands the firm's capital stock and disfavor a DER that reduces this stock.[60]

Ofgem's TOTEX-based policy is designed to mitigate any systematic preference a T&D company might have for or against capital-intensive production technologies. In essence, the policy specifies a revenue requirement that reflects the total cost the company is expected to incur when it employs what is judged to be an efficient mix of capital and non-capital inputs. Because the revenue requirement does not vary with the company's actual mix of capital and non-capital inputs during the term of the regulatory plan, the company will have increased incentive to substitute a capital-reducing DER for a more capital-intensive technology when (and only when) the former reduces the company's total cost of production. However, if observed capital expenditures at the end of a regulatory plan inform the revenue requirement for the next regulatory plan, a TOTEX-based policy typically will not immediately induce the cost-minimizing mix of capital and non-capital inputs.[61]

In settings where the prevailing regulatory policy provides T&D companies with insufficient incentive to implement capital-reducing DERs and NWAs, these incentives can be enhanced by promising the T&D company an ongoing share of the permanent cost reduction the DER project secures. Regulators in New York State have implemented a program that awards utilities 30% of the cost savings that arise from NWAs that reduce the need for additional network

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[58] See MIT Energy (2016) for an informative discussion of DERs and NWAs.

[59] See Wolak (2018) and Astier et al. (2023), for example.

[60] See MIT Energy (2016, chapter 5), for example. Vertically-integrated utilities can be reluctant to implement DERs that reduce customer demand for electricity (thereby reducing revenue from supplying electricity).

[61] See Ofgem (2013, pp. 30-32), MIT Energy (2016, p.150), Bovera (2021), and Brunekreeft and Rammerstorfer (2021).

investment.[62] Although such ongoing gain sharing can reduce the benefits that consumers derive from successful NWAs, the gain sharing can encourage the utility to identify, implement, and support promising DER projects, thereby promoting an overall reduction in network costs.

The fraction of realized cost savings from successful DERs and NWAs that is optimally awarded to the incumbent T&D company varies with prevailing industry conditions. Relevant conditions include the extent of the company's superior knowledge of the potential gains from particular DER projects and the diligence and effort required to ensure project success. It can be optimal to award the incumbent T&D company a relatively large fraction of the realized cost savings from a successful DER project when the company is particularly adept at promoting project success. The relatively large potential gain from success can help to motivate the company to fully employ its superior ability.[63]

Specific performance metrics and associated financial rewards are also being employed to encourage the deployment of DERs and NWAs. To illustrate, the Hawaii Public Utilities Commission (PUC) promises financial rewards to a T&D company that reduces the time required to interconnect a new DER system, increases the number of low- to moderate-income customers that participate in energy efficiency programs, or expands the peak demand curtailment secured by DERs (Hawaii PUC, 2018). Such targeted incentives to enhance particular elements of DER and NWA deployment can be coupled with more general incentives (e.g., gain sharing) to encourage the pursuit of all efficient DER projects.

To encourage entities other than the regulated utility to design and develop efficient DER projects, regulators often require utilities to publish detailed information about their distribution networks and to identify locations where DERs are particularly likely to have substantial potential to reduce costs.[64] Some worry that even when a utility disseminates key network information

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[62] See New York Public Service Commission (2017), Dyson et al. (2018), and Shen et al. (2021) for details of this and related reward structures.

[63] Brown and Sappington (2018, 2019) explain how DER procurement policies are optimally tailored to prevailing industry conditions. Regulatory policies also affect incentives for individuals to invest in DERs. Net metering has been employed in many jurisdictions to reward homeowners for generating electricity using solar panels. Under net metering, a homeowner is effectively paid for each unit of electricity he generates the unit price that the incumbent supplier charges for electricity. This unit price typically covers the full variable cost of supplying electricity and a portion of the associated fixed cost. Because net metering thereby provides compensation for distributed generation in excess of the corresponding cost saving for the incumbent electricity supplier, net metering can induce excessive DER investment (Brown and Sappington, 2017). For this reason, some regulators are reducing the rate at which customers are compensated for generating electricity (Apadula et al., 2023). Modified retail rate structures for electricity also can help to limit excessive investment in solar panels. Fixed charges for electricity can be increased, and variable charges can be reduced toward the incumbent supplier's unit variable cost of supplying electricity.

[64] For example, California's investor-owned utilities are required to publish detailed network topology information and information about other relevant network characteristics, including location-specific network hosting capacity (California PUC, 2014). In principle, the widespread dissemination of such

broadly, the utility may be inclined to favor its own DER projects over the projects proposed by alternative suppliers. To avoid this bias in the choice of DER projects, some jurisdictions (e.g., New York State) effectively preclude the incumbent T&D company from owning DERs (MIT Energy, 2016, p. 194).

The role of incumbent distribution utilities likely will change as DER technologies continue to evolve and expand. The utilities will need to operate as platforms that facilitate and manage the multi-directional flows of electricity among producers and consumers of electricity. To induce the companies to excel in this new role, incentives must be designed to reward the utility for reducing the long-term cost of supplying electricity by appropriately balancing traditional network investments and innovative investment in cost-effective DERs.[65]

7. Employing Incentive Regulation to Promote Environmental Goals.

The foregoing discussion has focused on the design of incentive regulation to maximize the welfare of electricity customers. However, policy makers often pursue additional goals, including environmental protection. Electricity production can entail the release of greenhouse gases that contribute to climate change. Consequently, expanded electricity production often is discouraged. In contrast, price cap regulation (PCR) typically encourages expanded electricity production. When the prevailing price of electricity exceeds the corresponding unit cost, the profit of an electricity supplier increases as its output increases. Alternatives to PCR can be advisable when regulators seek to reduce electricity production and consumption.

Average revenue regulation (ARR) is one possible alternative to PCR. ARR places a ceiling on the average revenue (rather than the price) a T&D company can secure. Average revenue is the ratio of total revenue to total output. When average revenue is capped, a reduction in output effectively authorizes an increase in the unit price (up to the level that keeps average revenue unchanged). Therefore, because reduced output entails reduced cost, ARR provides incentives for output reduction that PCR does not provide.[66,67]

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information could facilitate the competitive procurement of DER projects, much as key transmission assets are procured in some jurisdictions, including California (Joskow, 2019; California ISO, 2023, §8.4).

65 Such design can become particularly challenging when utility assets both facilitate network operations and serve energy markets. MIT Energy (2016, chapter 6) provides a detailed discussion of the development of distribution network platforms and the associated regulatory opportunities and challenges.

66 In principle, ARR can encourage a supplier to reduce its output substantially, even below the level a monopolist would supply (Comnes et al., 1995; Crew and Kleindorfer, 1996). In practice, such an outcome can be discouraged by limiting the rate at which prices can rise as output declines.

67 As noted above, the cost of supplying T&D service to an individual customer is primarily a fixed cost that does not vary with the volume of the customer's electricity consumption. Consequently, a fixed (non-volumetric) charge for T&D service can provide customers with efficient incentives for electricity

To further encourage an electricity supplier to promote reduced electricity consumption, the supplier might be rewarded for implementing energy efficiency programs. These programs often entail complementary or low-cost home inspections that can identify means by which homeowners can increase the efficiency of the electricity they consume. These means include increasing attic and wall insulation, enhancing window and door sealing, and purchasing more energy-efficient appliances.[68] When determining how to motivate an electricity supplier to design and implement an effective energy efficiency program, it is important to recognize that the supplier may not be naturally inclined to promote project success because such success can reduce the supplier's profit from electricity sales.

Rate structures with high fixed charges and low variable charges also can limit the incentive of an electricity supplier to expand output. When the variable charge for a unit of electricity is close to the corresponding cost of supply, the supplier's profit increases relatively slowly as output increases.[69] Of course, high fixed charges can impose financial hardship on customers with limited wealth. Therefore, as noted above, smaller fixed charges for financially-constrained customers can serve as a more equitable alternative to uniform fixed charges for all customers.[70]

8. Empirical Studies of the Effects of Incentive Regulation.

As the foregoing discussion indicates, many studies suggest that incentive regulation has considerable potential to enhance the performance of electricity T&D companies. A substantial and growing set of empirical studies find that this potential has been realized in practice. The ensuing discussion briefly summarizes the findings of selected studies. Hellwig et al. (2020) and Ajayi et al. (2022) provide more detailed and more comprehensive reviews of the literature.[71]

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consumption. A fixed charge can also limit the earnings risk that a T&D company faces from variation in electricity consumption. To the extent that a regulated ceiling on per-customer charges is divorced from the T&D company's realized infrastructure costs, the ceiling can also limit incentives for inefficiently large levels of infrastructure investment.

[68] In practice, the costs of energy efficiency programs often exceed the reduction in customer expenditures on energy that the programs induce (e.g., Fowlie et al., 2018). However, programs that subsidize efficiency-enhancing activities can enhance the welfare of those that receive the subsidies (e.g., low-income households). See Brown et al. (2020), for example.

[69] Low variable charges can encourage customers to increase their electricity consumption and their purchase of assets that are powered by electricity (e.g., electric vehicles). The expanded electricity consumption that arises when variable charges are reduced toward marginal cost can enhance welfare in the short run, particularly if additional network investment is not required to meet the increased demand for electricity.

[70] See Borenstein and Bushnell (2022) and Borenstein et al. (2022), for example.

[71] Sappington and Weisman (2010) review selected empirical studies of the effects of incentive regulation in other sectors.

Several empirical studies have examined the impact of incentive regulation on the operating costs and the productivity of electricity T&D companies.[72] To illustrate, Hellwig et al. (2020) report that the cost reductions achieved by German T&D companies between 2010 and 2013 increased as the corresponding financial incentives for cost reduction increased. Domah and Pollitt (2001) find that the privatization and price cap regulation introduced in the U.K. in 1985 promoted substantial increases in the productivity of T&D companies. Similarly, Hattori et al. (2005) report that between 1985 and 1998, U.K. T&D companies (that operated under PCR) experienced more rapid productivity growth than their Japanese counterparts (that operated under COSR). Ajayi et al. (2022) find that more stringent incentive regulation plans are associated with more rapid productivity growth for T&D companies in the U.K. between 1980 and 2019. Agrell et al. (2005) and Senyonga and Bergland (2018) report that Scandinavian electric utilities tend to achieve particularly rapid productivity growth under yardstick regulation.

The evidence regarding the impact of incentive regulation on the service quality that electricity T&D companies deliver is more mixed. Domah and Pollitt (2001) report increased service quality in the U.K. between 1985 and 1998, when the recently-privatized T&D companies operated under PCR. In contrast, Ter-Martirosyan and Kwoka (2010) find that incentive regulation was associated with service interruptions of longer duration in the U.S. between 1993 and 1999. However, corresponding reduced service quality did not arise in jurisdictions where the incentive regulation plan included explicit financial penalties for sub-standard service quality. Similarly, Ajayi et al. (2022) find evidence of increased service quality in the U.K. when incentive regulation plans include explicit financial incentives for improved service quality.

9. Conclusions.

Regulation that replicates the discipline of competitive markets can enhance the welfare of electricity consumers. However, replicating competitive discipline is challenging when regulators have limited knowledge of relevant industry conditions and their policy instruments are restricted. Incentive regulation attempts to harness the regulated firm's superior knowledge of industry conditions to achieve regulatory objectives. The best way to do so varies with the regulator's information, objectives, and instruments. No single incentive regulation plan is ideal in all settings.

We have examined how incentive regulation can be designed to reduce operating costs and promote efficient levels of service quality, network investment, and energy conservation. We have focused on the appropriate design of incentives for electricity suppliers, while noting the potential gains from also creating desirable incentives for electricity consumers.

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[72] Cambini and Rondi (2010) and Cullmann and Nieswand (2016) provide evidence of increased network investment by European electric utilities when they operate under incentive regulation.

For expositional ease, we have discussed separately incentive regulation plans to promote distinct objectives such as enhancing network reliability, inducing efficient levels of network investment, and reducing electricity production and consumption. However, it is important to view these plans as an integrated whole and to consider carefully how incentives to enhance performance on one dimension affect incentives for performance on other dimensions.

To illustrate, the promise of substantial rewards for improving network reliability can motivate a T&D operator to increase investment that serves this purpose. To limit excessive capital investment, it can be useful to enhance incentives for capital conservation when explicit incentives for enhanced network reliability are implemented. Enhanced incentives for capital conservation also can be appropriate when demand response programs substantially reduce the maximum demand for electricity. The presence of a robust demand response program also can reduce the need to implement strong incentives for the electricity supplier to reduce electricity sales.[73]

Incentive regulation can be controversial in practice, in part because it can allow regulated firms to earn substantial extranormal profit. Some may view unusually high levels of profit as a sign that regulators have failed to serve the best interests of consumers. However, incentive regulation is based on the principle that all parties can gain simultaneously. Consumers may only enjoy low prices and high levels of service quality because regulators employed the prospect of enhanced earnings to induce regulated suppliers to achieve favorable outcomes for consumers. Thus, extranormal profit may be a sign that incentive regulation is working to benefit consumers, not that the regulation has failed consumers. Consumer advocates may better appreciate this conclusion if they are active participants in the design of incentive regulation.[74]

Energy regulators around the world have implemented a wide variety of incentive regulation plans for many years now. Ubiquitous sharing of experiences with incentive regulation – both successes and failures – would be valuable. Additional empirical research that systematically controls for relevant differences across regulatory jurisdictions also is needed to identify the particular forms of incentive regulation that best achieve desired goals in specific environments.

Future research might also focus on ways to ensure ongoing industry innovation as diverse operating technologies (including DERs and NWAs) continue to emerge, and as demands for electricity change (reflecting, for example, pressures for electrification of the heating and transportation sectors). Profit sharing policies promote some incentive for innovation, but may be insufficient to induce efficient levels of innovation. Supplemental policies that explicitly promote

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73 See Joskow (2014) for additional discussion of the importance of carefully integrating all elements of an incentive regulation plan.

74 Littlechild (2009) examines the potential merit of early consumer involvement in the regulatory process. Ofgem expedites the approval of business plans that distribution companies formulate in collaboration with consumer advocates (Mandel, 2014).

innovation, such as those implemented by Ofgem (Thomas, 2023), may deliver long-term benefits to consumers that outweigh the corresponding short-term costs.

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