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Crew and Kleindorfer Effect Revisited: Impacts of Network Revenue Caps on Energy Market Competition and Consumer Welfare

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Abstract

Revenue cap regulation is increasingly used in energy network monopolies, despite longstanding concerns it can induce regulated firms to set super-monopoly prices – the so-called Crew and Kleindorfer Effect. This effect is replicated when energy demand is a function of both regulated transportation prices and imperfectly competitive energy prices. However, the incidence of the effect, and whether supplementary price regulation is needed to ensure sub-monopoly pricing, is shown to depend on network ownership type, and an assumption of positive marginal network costs. Regulated network prices are shown to preempt choices by oligopolistic energy firms, with an inverse relationship between network prices and energy prices, output, firm profits, and customer utility. Notably, increased energy market competition worsens the Crew and Kleindorfer Effect, representing a novel adverse consequence of such competition. Finally, regulated and unregulated customer ownership of networks – like investor ownership with sub-monopoly pricing – are predicted to maximize customer welfare. This suggests a need for coordination between network and energy market regulators, and differentiated regulation of customer- and investor-owned networks.

JEL classifications: L51, L13, D43, L94, L95.

Keywords: Revenue caps; Network regulation; Electricity and gas markets; Imperfect competition.

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1 Introduction

Revenue cap regulation, in which network monopolies' revenues are capped by regulators at some level below their unrestricted monopoly level, is increasingly becoming the predominant form of performance-based regulation in energy sector network monopolies (Weisman (2025)). While this form of regulation has some advantages over its main alternative, price cap regulation,[1] it has long-been known to also have undesirable features that could reduce consumer welfare.

In particular, Crew and Kleindorfer (1996a) were first to document that revenue cap regulation presents regulated firms with a choice between either a sub-monopoly price or a super-monopoly price.[2] Both of these prices satisfy the firm's revenue cap, but with the latter price resulting in worse consumer welfare than even the unregulated monopoly price. If the regulated firm has positive marginal costs, it is predicted to opt for the super-monopoly price since that satisfies the revenue cap but offers higher profits, given it involves lower output and hence lower total cost than the alternative sub-monopoly price. Comnes et al. (1995) describe this incentive of the regulated firm to opt for the super-monopoly price as the "Crew and Kleindorfer Effect", and propose a supplementary price cap to force the regulated firm to adopt the sub-monopoly price.

A potential limitation of this analysis is that it considers network monopoly demand independent of the demand for the energy that is typically produced by third parties and transported on the relevant network. In reality, consumers of energies like electricity or gas bundle their consumption of energy and its transportation as part of the business (maximizing profits) or household (maximizing utility) production decisions that give rise to their derived energy demands.[3]

Furthermore, in deregulated electricity or gas energy markets it is common for energy to be supplied by oligopolistically competitive firms. These firms are often vertically integrated between energy production and retailing, as a structural means to manage otherwise severe energy wholesale price risks. Since all such firms in a given energy market face the same transportation

[1]For example, Campbell (2018) mentions better resolution of volumetric risks, while Weisman (2025) refers to improved energy conservation.

[2]Comnes et al. (1995) first published this prediction, citing a prepublication version of Crew and Kleindorfer (1996a).

[3]In some jurisdictions energy and transportation are charged for separately, while in others, transportation charges are included alongside energy charges in energy retailer invoices to consumers (i.e. effectively treating transportation charges as a pass-through cost for the energy retailer).

charges from the relevant network monopoly, regulation of that network's price preempts competitive decisions by energy suppliers and hence energy prices, which are ultimately constrained by consumer demand.

Finally, the Crew and Kleindorfer Effect arises in the context of regulating an otherwise profit-maximizing network monopoly. While this can be considered an accurate characterization of investor-owned network monopolies, many such networks are owned by their customers.[4] In that case, objectives more related to consumer welfare and not solely focused on profit-maximization are likely to apply. As we show, network ownership affects whether regulated firms opt for either the sub- or super-monopoly transportation price when facing revenue caps.

The incentives for network monopolies to choose either sub- or super-monopoly prices under revenue cap regulation, and the ultimate consumer welfare effects of that choice, are therefore necessarily mediated by both network ownership, and by how network prices affect energy prices set by imperfectly competitive energy firms. In other words, choices made by regulators and regulated network monopolies affecting transportation prices both constrain, and are affected by, the nature and extent of competition in related energy markets, with those choices further affected by network ownership type.

This paper revisits the Crew and Kleindorfer Effect by addressing each of the above limitations. First, energy demand – e.g. for electricity, or for gas – is derived as part of a household utility maximization, to explicitly account for how that demand – and consumers' utility – is affected jointly by transportation and energy prices. Second, a sequential game is modeled in which the network monopoly subject to a revenue cap first chooses its transportation price, and then subject to that price, vertically integrated oligopolistic firms compete to produce and retail energy. Finally, the impact of network ownership type on resulting subgame choices, and on consumer welfare, is examined by allowing for both customer and investor ownership of the regulated network monopoly. To reflect the fact that transportation network costs are predominantly fixed,[5] the analysis proceeds under the simplifying

[4] In electricity distribution, for example, customer-owned cooperatives dominate in the rural U.S., with networks covering 56% of the country's landmass and supplying 42 million customers (NRECA (2025)). They also feature prominently in Latin America (Argentina, Bolivia, Brazil, Chile), parts of Asia (India, the Philippines, Bangladesh) and Spain (NRECA International (2010)), Italy (Doni and Mori (2014), all Scandinavian countries (Qasim et al. (2024)), and New Zealand (Meade and Söderberg (2020)).

[5] For example, studies of electricity distribution network costs in Canada (Yatchew (2000)) and economies of scale in New Zealand (Giles and Wyatt (1993)) find that energy throughput has statistically insignificant impacts. Furthermore, electricity networks have high build costs, but maintenance costs that bear little resemblance to electricity

but plausible assumption that marginal transportation costs are zero.[6]

With these extensions to the original Crew and Kleindorfer setting, we show that a network monopoly subject to revenue cap regulation continues to face a choice between sub- and super-monopoly prices. However, with network costs assumed entirely fixed and marginal network costs therefore being zero, an investor-owned network (maximizing profits) is indifferent between the two regulated prices, whereas a customer-owned network (maximizing total surplus) prefers the sub-monopoly price. Hence any supplementary price caps to force selection of the sub-monopoly price may be unnecessary if the regulated networks are customer-owned. More particularly, transportation price is lowest and identical under either regulated customer ownership, or regulated investor ownership with sub-monopoly price chosen. An unregulated customer-owned firm chooses a transportation price at least as high as that price (to ensure break-even), which is strictly less than the unregulated investor-owned monopoly price, with the super-monopoly price under investor ownership highest overall.

In the energy market subgame, total energy output, energy price, energy firm profits, and consumer utility, are all found to be decreasing in transportation price – though importantly, energy prices change by a smaller magnitude than transportation prices, but any beneficial effects of this on consumers are outweighed by changes in total energy output. As such, energy prices, total output, energy firm profits – and importantly, customer utility – are all highest when transportation prices are chosen by networks under regulated customer ownership, or regulated investor ownership with the sub-monopoly price chosen. They are at least as high under unregulated customer ownership, but strictly lower under unregulated investor ownership, and lowest overall under regulated investor ownership with super-monopoly transportation price chosen.

Finally, as energy market competition intensifies, the inverse relationship between transportation prices and both energy prices and energy firm profit becomes weaker, while that with both energy output and consumer utility becomes stronger. Importantly, more intense energy market competition worsens the Crew and Kleindorfer effect, causing a regulated network's sub-monopoly energy transportation to fall, but its super-monopoly price to rise, with a corresponding worsening in consumer welfare if the super-monopoly price is selected. To our knowledge, this consequence of increased energy market competition has not been previously identified. Conversely, such

throughput (Harris (2014)).

[6] For present purposes, this also requires that transportation losses are negligible, or not a cost to the network, which is also assumed.

increased competition is associated with lower energy transportation prices if the network is customer-owned, which too is a novel finding.

More generally, we confirm the Crew and Kleindorfer Effect's negative impact on customer welfare in a richer setting, including through its impact on energy market outcomes. However, we also show that this negative effect of revenue cap regulation rests on both investor ownership of the regulated firm, and on the presence of non-zero marginal transportation costs, with regulated customer ownership (or regulated investor ownership with a supplementary price cap) guaranteeing choice of sub-monopoly pricing and hence maximizing consumer utility.

We therefore identify an important externality of revenue cap regulation, given higher transportation prices lead to more intense energy market competition. However, that positive externality is shown to be insufficient to reverse the adverse consumer welfare impacts of higher transportation prices. This points to a need for greater coordination between network and energy market regulators, given choices by one affect the effectiveness and consequences of choices by the other. Our findings also point to a need to differentiate regulation of customer- and investor-owned networks, with the case for regulation weaker under customer ownership, but more compelling under investor ownership (in which case supplementary price caps are more likely to be beneficial).

This study extends the longstanding literature on the merits or otherwise of revenue cap regulation in network monopolies (e.g. Crew and Kleindorfer (1996a, 1996b), Lantz (2008)), including relative to price regulation (e.g. Campbell (2018), Weisman (2025)).[7] It also extends studies identifying in general terms the implications of network regulation for competition in wholesale and retail markets (e.g. Joskow (2008)), and the impacts of legal unbundling of network monopolies on downstream energy market competition (e.g. Heim et al. (2018)). It further complements those analyzing the competitive impacts of transmission – rather than transmission regulation *per se* – on electricity markets (e.g. Borenstein et al. (2000), Contreras and Gross (2004), Sauma and Oren (2006), Yao et al. (2008), Downward et al. (2010)).

Closest to this study is Bennett (2002), which examines the benefits of coordinating gas transportation regulation with the subsequent regulation of electricity transportation, assuming profit maximizing networks. In that study gas is used for electricity generation, and like here, an externality arises between different stages of production. However, here it is between regulated

[7]For a recent review of lessons from 40 years of incentive regulation, see Sappington and Weisman (2024)).

firms' price choices and those of downstream competing firms, rather than between sequential regulators, and with imperfect competition assumed in energy production and retailing (Bennett assumes marginal cost pricing for both gas and electricity supply). Also, we analyze the competition and consumer welfare implications of revenue caps, while Bennett analyzes average revenue regulation. Bennett's analysis points to a need for a joint regulatory body to resolve the pricing externality between regulators, while this study highlights the interplay between regulation and competition in related markets, and between ownership and regulation in determining the optimal application of revenue cap regulation.

The balance of this paper is structured as follows. Section 2 sets out our model, with results presented in Section 3. Section 4 concludes.

2 Model

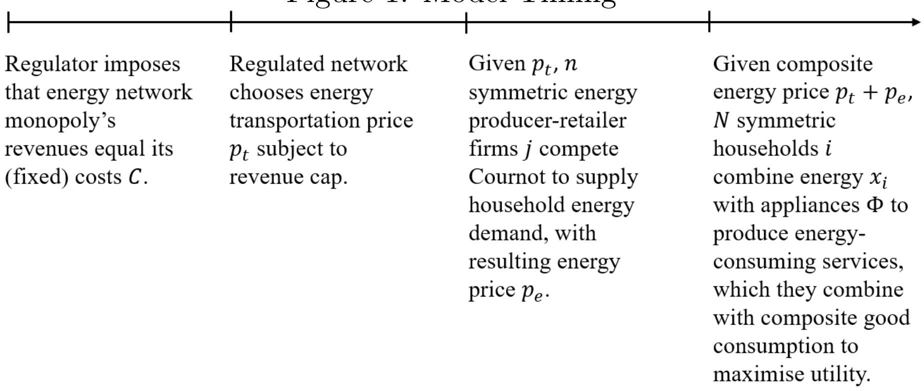
2.1 Setting

We focus on a single energy sector, like electricity, supplying household demand with energy and energy transportation services assumed bundled in $1-1$ fixed proportions. As illustrated in Figure 1, we consider a sequential game in which a regulator first imposes that the energy network monopoly's revenues must equal its (fixed) costs C. Subject to this revenue cap, and anticipating how its price choice affects subsequent energy market competition, the regulated network chooses its transportation price p_t such that its revenue with demand $x(p_t)$ equals C – i.e. such that $p_t x(p_t) = C$, and hence so its regulated profits are $\Pi_t(p_t) = 0$.

Then, given p_t, $n > 1$ symmetric Cournot producer-retailers $j = 1, ..., n$ (e.g. "gentailers", both generating and retailing electricity) compete simultaneously in energy quantities x_j to supply energy – at resulting energy price p_e – demanded by N identical utility-maximizing households $i = 1, ..., N$. Those households' symmetric energy demands are derived as a consequence of consuming both energy-consuming services z_{i1} (created by combining energy with exogenous appliances stock $\Phi > 0$), and a composite good z_{i2}. The aggregate energy price paid by households is $p_t + p_e$, while the price of the composite good is normalized to one, and each household has identical exogenous income y.

Having energy market competition follow network regulation and energy transportation price choice can be motivated by the fact that network regulation typically applies for fixed periods (e.g. five years) between resets, whereas energy market competition – for given production capacities – can

Figure 1: Model Timing



occur as frequently as intra-day.

2.2 Household Energy Demand

Representative household i has quadratic quasi-linear utility (with $a > 0$ and $b > 0$ assumed):

$$U_i\left(z_{i1}, z_{i2}\right) = az_{i1} - \frac{b}{2}z_{i1}^2 + z_{i2} \tag{1}$$

which it maximizes subject to the following technology constraint relating to how energy consumption x_i and appliances Φ produce energy-consuming services:

$$z_{i1} = \Phi x_i \tag{2}$$

and income constraint (assumed binding):

$$y_i = \left(p_t + p_e\right) x_i + z_{i2} \tag{3}$$

Since we later consider the case of a customer-owned network, which might distribute a share of network profits Π_t to each of the N households that own it, in principle (3) could include additional income Π_t/N. However, we ignore this on *de minimis* grounds, since the profit share in practice would represent a negligible proportion of household income,[8] and because it also simplifies the analysis without loss of generality. Instead, the customer-owned network is assumed to benefit its customers via its choice of p_t, as shown below.

[8] For example, in the author's home city of Auckland, New Zealand, the local electricity network company Vector is predominantly customer-owned, and pays (via its parent trust, Entrust) an annual dividend of NZ$350. This compares with a median annual income of around NZ$125,000 for households in the qualifying area.

The representative household's utility is found by solving (3) for z_{i2}, and substituting that – and (2) for z_{i1} – into (1):

$$U_i\left(x_i, p_e, p_t\right) = -\frac{b\Phi^2 x_i^2}{2} + \left(a\Phi - p_e - p_t\right) x_i + y_i \tag{4}$$

Maximizing the resulting expression with respect to energy demand yields household i's utility-maximizing derived energy demand:[9]

$$x_i\left(p_e, p_t\right) = \frac{a\Phi - p_e - p_t}{\Phi^2 b} \tag{5}$$

which aggregates across the N symmetric households to yield total energy demand (which also equals total transportation demand assuming nil transportation losses):

$$x\left(p_e, p_t\right) = \frac{N\left(a\Phi - p_e - p_t\right)}{\Phi^2 b} \tag{6}$$

Notice that p_t is necessarily less than $a\Phi$ for aggregate energy demand to be positive at any positive p_e, so we assume throughout that $a\Phi$ is sufficiently high that $p_t < a\Phi$ is assured.

Finally, inverse demand using (6) is:

$$p_e\left(x, p_t\right) = \frac{\left(a\Phi - p_t\right) N - x\Phi^2 b}{N} \tag{7}$$

2.3 Energy Market Competition

Each of $n > 1$ symmetric energy producer-retailers j with quadratic costs (to approximate capacity constraints) has profit function:

$$\Pi_j = p_e\left(x, p_t\right) x_j - \frac{c}{2} x_j^2 \tag{8}$$

with $c > 0$ assumed. Each firm's best response function – i.e. its profit-maximizing output choice x_j, taking the output choices of its rivals x_{-j} as given – is found by substituting inverse demand (7) and denoting aggregate energy demand as $x \equiv x_j + x_{-j}$ in (8), and maximizing the resulting profit function with respect to x_j. Given symmetric firms, we can denote $x_j = X$

[9]The relevant second order condition is satisfied given the negative quadratic structure of U_i and assumed parameter signs.

and $x_{-j} = (n-1)X$, which when substituted in energy firm j's best response function yields that firm's subgame perfect equilibrium output:[10]

$$x_j(p_t) = \frac{(a\Phi - p_t)N}{b(n+1)\Phi^2 + Nc} \tag{9}$$

which aggregates across the n firms to produce subgame perfect equilibrium market output:

$$x(p_t) = \frac{n(a\Phi - p_t)N}{b(n+1)\Phi^2 + Nc} \tag{10}$$

As above, $p_t < a\Phi$ is assumed, which ensures subgame perfect equilibrium energy output and price are both positive. Using (10) in (7), the resulting subgame perfect equilibrium energy price is thus:

$$p_e(p_t) = \frac{(a\Phi - p_t)(\Phi^2 b + Nc)}{b(n+1)\Phi^2 + Nc} \tag{11}$$

Substituting (9) and (11) into (8) yields energy firm j's subgame perfect equilibrium profit:

$$\Pi_j(p_t) = \frac{(a\Phi - p_t)^2 N(2\Phi^2 b + Nc)}{2(b(n+1)\Phi^2 + Nc)^2} \tag{12}$$

Finally, using (10) for $x(p_t)$, and noting that symmetric household i's subgame perfect equilibrium demand is $x_i(p_t) = x(p_t)/N$, subgame perfect equilibrium utility for household i is found by substituting this expression and (11) into (4), yielding:

$$U_i(p_t) = \frac{\Phi^2 bn^2}{A}p_t^2 - \frac{2\Phi^3 abn^2}{A}p_t + \frac{\Phi^4 a^2 bn^2}{A} + y_i \tag{13}$$

where we hereafter simplify notation by defining $A \equiv 2(b(n+1)\Phi^2 + Nc)^2$, with $A > 0$. The derivatives of these subgame perfect equilibrium results with respect to p_t are presented in Section 3, which allow ranking of the household welfare and energy market competition implications of the network firm's regulated and unregulated transportation price choices, under both investor and customer ownership.

[10]The relevant second order condition is satisfied given the negative quadratic structure of Π_j and assumed parameter signs.

2.4 Benchmark: Unregulated Energy Transportation Price

2.4.1 Case 1: Investor-Owned Network

Given its costs are assumed to be fixed amount C, and only variable transportation prices are assumed, the transportation network monopoly's profits are:

$$\Pi_t(p_t) = p_t x(p_t) - C \tag{14}$$

Substituting for $x(p_t)$ using (10) and taking the first order condition with respect to p_t yields an unregulated investor-owned (UIO) network's monopoly transportation price:[11]

$$p_t^{UIO} = \frac{a\Phi}{2} \tag{15}$$

In Section 3.1 it is assumed that a revenue cap in the regulated investor-owned (RIO) case satisfying $\Pi_t\left(p_t^{RIO}\right) = 0$ results in a lower profit than in the UIO case – i.e. that the revenue cap is binding. As such, it can be assumed here that $\Pi_t\left(p_t^{UIO}\right) > 0$. Also, note that p_t^{UIO} is invariant to the number n of competing energy firms it serves, which we return to in Section 3.3.

2.4.2 Case 2: Customer-Owned Network

An unregulated customer-owned (UCO) network – otherwise identical to the UIO network except for its ownership structure – is assumed to maximize total surplus $W(p_t)$,[12] which writes as follows assuming N symmetric households i:

$$W(p_t) = \Pi_t(p_t) + U_i(p_t) N \tag{16}$$

Deferring consideration of the UCO network's break even constraint to Section 3, the surplus-maximizing price is found using (13) and (14) in (16) and taking the first order condition with respect to p_t, yielding:[13]

$$p_t^{UCO} = \frac{a\Phi\left(\Phi^2 b + Nc\right)}{\Phi^2 bn + 2\Phi^2 b + 2Nc} \tag{17}$$

[11] The relevant second order condition is satisfied given the negative quadratic structure of Π_t and assumed parameter signs.

[12] While a profit share was earlier excluded from the representative household's budget constraint on *de minimis* grounds, a customer-owned network is nonetheless assumed to value its ability to make a cash distribution to its customers, or at least to break even in order to viably continue to serve its customers.

[13] The relevant second order condition is satisfied, with the concavity in p_t of $\Pi_t(p_t)$ dominating the convexity of $U_i(p_t) N$.

By calculating $p_t^{RIO} - p_t^{UCO}$ directly using (15) and (17) it can be readily shown that $p_t^{UCO} < p_t^{UIO}$. These findings are summarized in the following lemma:

Lemma 1: Unregulated Energy Transportation Prices

Under the maintained assumptions:

(a) An unregulated investor-owned network charges profit-maximizing price: $p_t^{UIO} = \frac{a\Phi}{2}$;

(b) An unregulated customer-owned network charges surplus-maximizing price: $p_t^{UCO} = \frac{a\Phi\left(\Phi^2 b + Nc\right)}{\Phi^2 bn + 2\Phi^2 b + 2Nc}$; and

(c) $p_t^{UCO} < p_t^{UIO}$.

3 Results

3.1 Regulated Energy Transportation Price

3.1.1 Case 1: Investor-Owned Network

We now assume that the network regulator caps the network firm's revenues such that its profits are zero, which means in the *RIO* case that we have:

$$\Pi_t\left(p_t^{RIO}\right) = 0 \Leftrightarrow p_t^{RIO} x\left(p_t^{RIO}\right) = C \tag{18}$$

Using (10) for $x(p_t)$ in (18), and defining A as for (13), this means p_t^{RIO} solves the following negative quadratic:

$$-\frac{nN}{\sqrt{A/2}} p_t^2 + \frac{nNa\Phi}{\sqrt{A/2}} p_t = C \tag{19}$$

As such, in general this implies two possible roots, from which the Crew and Kleindorfer effect arises. Specifically, solving (19), and using (15), yields:

$$p_t^{RIO} = \frac{a\Phi}{2} \pm \frac{\sqrt{B}}{2nN} \Leftrightarrow p_t^{RIO} = p_t^{UIO} \pm \frac{\sqrt{B}}{2nN} \tag{20}$$

where $B \equiv 4nN\left(\left(\frac{nNa^2}{4} - b(n+1)C\right)\Phi^2 - CNc\right)$.[14] The *RIO* network's sub- and super-monopoly prices – each satisfying the firm's zero profit revenue cap – are denoted:

$$p_{t,sub}^{RIO} \equiv p_t^{UIO} - \frac{\sqrt{B}}{2nN} < p_t^{UIO} \tag{21}$$

[14] It can be shown that $B > 0$ provided N is not "too large".

$$p_{t,sup}^{RIO} \equiv p_t^{UIO} + \frac{\sqrt{B}}{2nN} > p_t^{UIO} \tag{22}$$

Since the network's costs C are assumed entirely fixed, a RIO network should be indifferent between either $p_{t,sub}^{RIO}$ and $p_{t,sup}^{RIO}$, given its profits are the same – i.e. zero – in either case. As such, a supplementary price cap to induce selection of $p_{t,sub}^{RIO}$ may be desirable, but not essential. By contrast, Crew and Kleindorfer (1996a) assume a RIO network has positive marginal transportation costs, in which case its profits are maximized by choosing $p_{t,sup}^{RIO}$. This more strongly motivates the imposition of such a supplementary price cap.

Finally, Lemma 1(c) indicates that an UCO network would charge a lower price than an otherwise-identical UIO network – i.e. that $p_t^{UCO} < p_t^{UIO}$. Hence, since the RIO network only breaks even at $p_{t,sub}^{RIO}$, for an otherwise-identical UCO network with the same profit function to break even, it must be the case that $p_t^{UCO} \geq p_{t,sub}^{RIO}$. Thus we have:

$$p_{t,sub}^{RIO} \leq p_t^{UCO} < p_t^{UIO} < p_{t,sup}^{RIO} \tag{23}$$

3.1.2 Case 2: Customer-Owned Network

A regulated customer-owned (RCO) network has the same profit function – and faces the same revenue cap – as a RIO network that is otherwise identical except for ownership. This means the RCO network faces the same two possible transportation prices as the RIO network, i.e. $p_t^{UIO} \pm \sqrt{B}/2nN$.

However, since its regulated profits are zero, a RCO network maximizing surplus (16) will simply choose whichever transportation price maximizes total customer utility, $U_i(p_t)N$, which is equivalent to maximizing representative customer utility $U_i(p_t)$ given customers are assumed symmetric.

Intuitively, this requires a RCO network to choose the sub-monopoly transportation price. To show this formally, differentiating (13), and recalling that $p_t < a\Phi$ by assumption, we have:

$$\frac{\partial U_i(p_t)}{\partial p_t} = -\frac{b\Phi^2 n^2 (a\Phi - p_t)}{A/2} < 0 \tag{24}$$

This means a RCO network will indeed opt for the sub-monopoly price over the super-monopoly price, since this results in higher customer welfare, i.e.:

$$p_t^{RCO} = p_{t,sub}^{RIO} = p_t^{UIO} - \frac{\sqrt{B}}{2nN} \tag{25}$$

Combining (23) and (25), and using (24), we have our first proposition:

Proposition 1 – Regulated and Unregulated Energy Transportation Prices and Customer Welfare under Customer and Investor Ownership:

Under the maintained assumptions, with B as defined for (20), and denoting total customer welfare as $U(p_t) \equiv U_i(p_t) N$:

(a) $p^{RIO}_{t,sub} = p^{UIO}_t - \frac{\sqrt{B}}{2nN}$;

(b) $p^{RIO}_{t,sup} = p^{UIO}_t + \frac{\sqrt{B}}{2nN}$;

(c) $p^{RCO}_t = p^{RIO}_{t,sub} \leq p^{UCO}_t < p^{UIO}_t < p^{RIO}_{t,sup}$; and

(d) $U\left(p^{RIO}_{t,sup}\right) < U\left(p^{UIO}_t\right) < U\left(p^{UCO}_t\right) \leq U\left(p^{RIO}_{t,sub}\right) = U\left(p^{RCO}_t\right)$.

Figure 2 illustrates Proposition 1(c) graphically. Since network marginal costs are assumed to be zero, network profits are maximized when revenue is maximized, yielding p^{UIO}_t. With a binding revenue cap, such that less than maximal profits can be obtained, an investor-owned network satisfies that cap at either a sub-monopoly price $p^{RIO}_{t,sub}$, or super-monopoly price $p^{RIO}_{t,sup}$, and in our setup (in contrast to Crew & Kleindorfer's) is indifferent between the two.

Conversely, if the regulated network is customer-owned, it chooses $p^{RCO}_t = p^{RIO}_{t,sub}$ to maximize customer welfare. However, if a customer-owned network is unregulated, it chooses a transport price less than that chosen by an unregulated investor-owned network, but to break even must charge a price at least as great as $p^{RIO}_{t,sub}$, so we have $p^{RIO}_{t,sub} \leq p^{UCO}_t < p^{UIO}_t$ as shown.

3.2 Impacts of Network Price Choices on Energy Market Competition

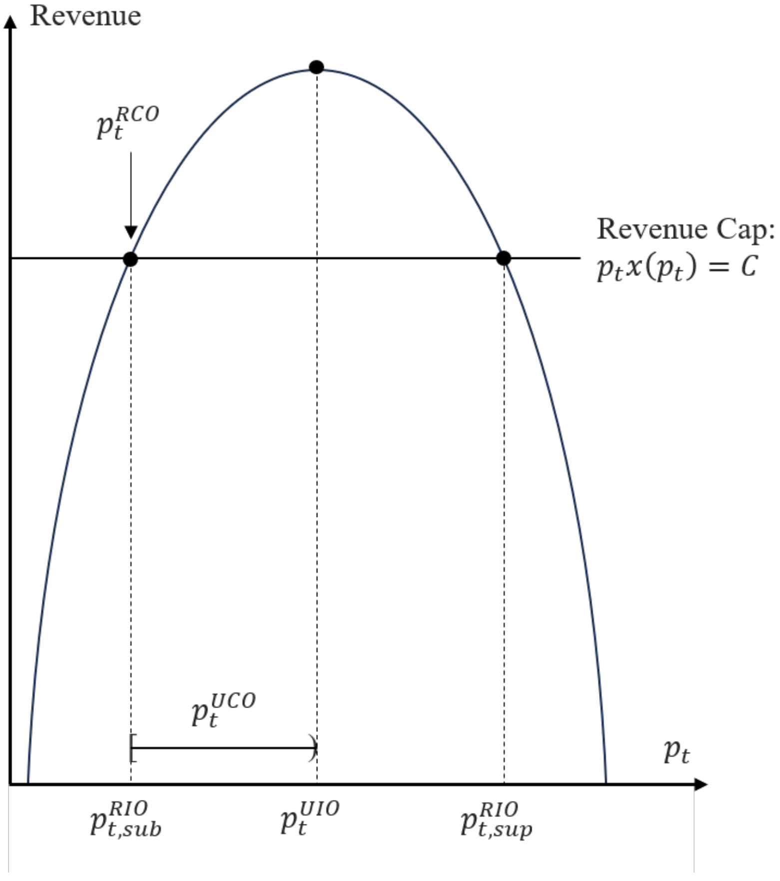
By directly differentiating the energy market subgame perfect equilibrium results (10), (11) and (12) with respect to p_t, recalling that $p_t < a\Phi$ by assumption, and using $A > 0$ as defined for (13), we have:

$$\frac{\partial x(p_t)}{\partial p_t} = -\frac{nN}{\sqrt{A/2}} < 0 \tag{26}$$

$$\frac{\partial p_e(p_t)}{\partial p_t} = -\frac{\Phi^2 b + Nc}{\sqrt{A/2}} < 0 \tag{27}$$

$$\frac{\partial \Pi_j(p_t)}{\partial p_t} = -\frac{(a\Phi - p_t) N (2\Phi^2 b + Nc)}{A/2} < 0 \tag{28}$$

Figure 2: Regulated and Unregulated Energy Transportation Prices under Customer and Investor Ownership



Importantly, $\sqrt{A/2} > \Phi^2 b + Nc$, so from (27) we further have:

$$-1 < \frac{\partial p_e(p_t)}{\partial p_t} < 0 \tag{29}$$

Hence, while a rise in p_t induces a reduction in p_e, the reduction is insufficient to fully offset that rise. Since it also induces a reduction in energy output x, a rise in p_t unambiguously reduces energy firms' profits, as shown by (28).

Combining the above derivatives with Proposition 1(c) results in Proposition 2:

> **Proposition 2** – Energy Market Output, Price and Firm j Profits arising from Regulated and Unregulated Network Prices under Investor and Customer Ownership
>
> Under the maintained assumptions:
>
> (a) $x\left(p_{t,sup}^{RIO}\right) < x\left(p_t^{UIO}\right) < x\left(p_t^{UCO}\right) \leq x\left(p_{t,sub}^{RIO}\right) = x\left(p_t^{RCO}\right)$;
>
> (b) $p_e\left(p_{t,sup}^{RIO}\right) < p_e\left(p_t^{UIO}\right) < p_e\left(p_t^{UCO}\right) \leq p_e\left(p_{t,sub}^{RIO}\right) = p_e\left(p_t^{RCO}\right)$; and
>
> (c) $\Pi_j\left(p_{t,sup}^{RIO}\right) < \Pi_j\left(p_t^{UIO}\right) < \Pi_j\left(p_t^{UCO}\right) \leq \Pi_j\left(p_{t,sub}^{RIO}\right) = \Pi_j\left(p_t^{RCO}\right)$.

Proposition 2 shows that a higher energy transportation price choice by the network firm, all other things being equal, results in lower energy market price and output, and also a lower profit for energy firms, and *vice versa*. In other words, in particular this means that transportation and energy prices are strategic substitutes. However, since regulation dictates transportation prices – and assuming unregulated prices of networks are similarly pre-committed (i.e. by virtue of network ownership choice being given, and harder/slower to change than energy prices) – our results show that energy firms' strategic choices are constrained by transportation price choices, in a manner akin to Stackelberg leadership by the network, albeit in different – though complementary – markets.

Furthermore, while customer ownership is in general more likely to yield lower transportation prices than investor ownership, and maximizes customer welfare, it is also more likely to yield higher energy prices and output, and higher energy firm profits. This points to a potential preference of both consumers and energy firms for networks to be customer-owned – particularly if the networks are unregulated, but also if regulated to choose $p_{t,sub}^{RIO}$.

These findings cast doubt on the merits of regulating customer-owned networks, since they can be expected to yield greater customer welfare. However, they also point to a likely unintended consequence of revenue cap regulation –

namely that if it succeeds in lowering energy transportation prices, it also increases energy prices and energy firm profits. This interdependency between transportation regulation and pricing on the one hand, and energy market outcomes on the other, indicate a possible need for respective network and energy market regulators to account for how their decisions affect the efficacy of each other's regulation.

3.3 Implications of Increasing Energy Market Competition

We considered above how regulated and unregulated energy transportation price choices rank under different forms of network ownership, and how this ranking translates into energy market output, price and producer-retailer firm profits. Here we explore how a change in the intensity of energy market competition – specifically, an increase in the number n of competing symmetric energy producing-retailing firms – affects our previous energy market and household welfare findings, as well as our findings regarding energy transportation price choices.

We do this, first, by considering how each of our earlier transportation price derivatives varies with n. Specifically, by differentiating each of (26), (27), (28) and (24) with respect to n, and recalling that $A > 0$ and by assumption $p_t < a\Phi$, we find:

$$\frac{\partial}{\partial n}\left(\frac{\partial x\left(p_t\right)}{\partial p_t}\right) = -\frac{N\left(\Phi^2 b + Nc\right)}{A/2} < 0 \tag{30}$$

$$\frac{\partial}{\partial n}\left(\frac{\partial p_e\left(p_t\right)}{\partial p_t}\right) = \frac{\left(\Phi^2 b + Nc\right)\Phi^2 b}{A/2} > 0 \tag{31}$$

$$\frac{\partial}{\partial n}\left(\frac{\partial \Pi_j\left(p_t\right)}{\partial p_t}\right) = \frac{2\left(a\Phi - p_t\right)N\left(2\Phi^2 b + Nc\right)\Phi^2 b}{A/2\sqrt{A/2}} > 0 \tag{32}$$

$$\frac{\partial}{\partial n}\left(\frac{\partial U_i\left(p_t\right)}{\partial p_t}\right) = -\frac{2n\left(a\Phi - p_t\right)\left(\Phi^2 b + Nc\right)\Phi^2 b}{A/2\sqrt{A/2}} < 0 \tag{33}$$

These results are summarized in Proposition 3:

Proposition 3 – Effects of Energy Market Competition Intensity on Energy Market and Consumer Outcomes

Under the maintained assumptions, as energy market competition – represented by the number n of competing energy producer-retailers – intensifies:

(a) Energy output x and representative household utility U_i each falls more strongly as energy transportation price rises; and

(b) Energy price p_e and energy firm profits Π_j each falls less strongly as energy transportation price rises.

From Proposition 3 we see that energy market competition mediates the interconnection between transportation price choices on the one hand, and energy market and household outcomes on the other, in a non-uniform way. While higher transportation prices are pro-competitive for energy market prices (i.e. result in lower energy prices), this effect weakens as energy market competition intensifies. Likewise for energy firm profits – higher transportation prices lower energy firm profits, but less so as energy market competition intensifies. Conversely, energy output and household welfare each fall as transportation price rises, and do so more strongly as energy market competition intensifies.

This is potentially important if either network or energy market regulators have regard to externalities they cause, or suffer from, in the two related markets. For example, while higher transportation prices may seem to induce desirable energy market externalities in the form of lower energy prices and energy firm profits, there are diminishing returns to extra energy market competition from doing so. However, the likely more important energy market externalities of a higher transportation price are the resulting declines in energy output and household utility, for which there are increasing returns to more intense energy market competition.

Finally, we consider how changes in energy market competition intensity affect energy transportation price choices. As noted earlier at (15), an unregulated investor-owned utility's monopoly price $p_t^{UIO} = {}^{a\Phi}/_{2}$ is invariant to n. Furthermore, by differentiating (21) and (22) with respect to n, using $B = B(n)$ as defined at (21), we find:

$$\frac{\partial p_{t,sub}^{RIO}}{\partial n} = -\frac{\left(\Phi^2 b + Nc\right) C}{n\sqrt{B}} < 0 \tag{34}$$

$$\frac{\partial p_{t,sup}^{RIO}}{\partial n} = \frac{\left(\Phi^2 b + Nc\right) C}{n\sqrt{B}} > 0 \tag{35}$$

Summarizing these findings, and further applying Proposition 1(c), we have Proposition 4:

Proposition 4 – Effects of Energy Market Competition Intensity on Energy Transportation Prices

Under the maintained assumptions, as energy market competition – represented by the number n of competing energy producer-retailers – intensifies:

(a) p_t^{UIO} remains unchanged;

(b) $p_{t,sub}^{RIO}$, and hence both p_t^{RCO} and $min\left(p_t^{UCO}\right)$, decrease; and

(c) $p_{t,sup}^{RIO}$ increases.

Proposition 4(c) is notable, since it means that the Crew and Kleindorfer Effect, if it arises, worsens as energy market competition intensifies. In effect, as such competition intensifies and energy price decreases, this increases the headroom for the super-monopoly regulated network price to rise. To our knowledge this potential negative externality of energy market competition on network pricing is novel, and represents a notable extension of the Crew and Kleindorfer Effect.

Conversely, Proposition 4(b) means that more intense energy market competition produces a positive externality for energy transportation pricing under regulated investor ownership of the network if sub-monopoly pricing is chosen, and also if the network is customer-owned. With lower energy price and higher output, the network revenue cap can be met with a lower sub-monopoly price. Furthermore, customer ownership in this case affords an additional source of consumer protection – insulating consumers from a potential adverse consequence of increased energy market competition. This too, to our knowledge, is an effect not previously documented.

4 Conclusions

We have revisited the Crew and Kleindorfer Effect in a more general setting, allowing for the interaction between network monopoly energy transportation pricing and oligopolistic energy pricing, and also for both customer and investor ownership of the relevant network. While the possibility of super-monopoly energy transportation pricing arises in our setting, in contrast to Crew and Kleindorfer (1996a) where marginal costs of energy transportation are positive, thus favoring the monopoly choosing the super-monopoly price, our simplifying assumption that network costs are entirely fixed means that a regulated investor-owed network will be indifferent between that price and the sub-monopoly price that also satisfies its revenue cap. This reduces – but does not remove – the need for a supplementary price cap to induce an investor-owned regulated network to select the sub-monopoly price.

We further extend this result by considering customer ownership of the network monopoly. Even without regulation such a network is inclined to select the sub-monopoly regulated price (which guarantees break even, and certainly chooses this price if regulated), or at least a price less than the unregulated price that an investor-owned network would select. Certainly the customer-owned network would not select the super-monopoly price, with or without regulation, obviating the need for a supplementary price cap, and possibly for regulation at all.

These results arise in a context where an externality arises between energy transportation pricing and subsequent oligopolistically competitive energy market pricing. More specifically, we have shown that transportation pricing constrains energy pricing, since consumers purchase the two as a fixed proportion bundle at the aggregate of transportation and energy prices. In particular, higher energy transportation prices induce lower energy market prices, output and firm profits, though not enough to improve consumer welfare. As such, network regulation – or customer ownership – have an important role to play in ensuring customer welfare is maximized.

Furthermore, we show that increasing energy market competition mediates the externality between energy transportation and energy market prices, though in a way that more importantly affects customer welfare. This raises a possible risk that regulators focus on how energy transportation prices result in apparently pro-competitive energy market outcomes, with conflicting consumer welfare outcomes, when attempting to encourage more intensive energy market competition.

Importantly, more intense energy market competition worsens the Crew and Kleindorfer effect, causing a regulated network's sub-monopoly energy transportation price to fall, but its super-monopoly price to rise, with a corresponding worsening in consumer welfare if the super-monopoly price is selected. To our knowledge, this consequence of increased energy market competition has not been previously identified. Conversely, such increased competition is associated with lower energy transportation prices if the network is customer-owned, which too is a novel finding.

Our findings indicate there may be benefits to greater coordination between network monopoly and energy market regulators, given they each affect the efficacy of their counterpart's regulation. Furthermore, they point to a need for differentiated regulatory approaches when energy transportation network monopolies are customer- rather than investor-owned.

Extensions to this study include allowing for multi-part tariffs, and possible retail price caps (covering energy as well as transportation prices). They also include allowing for the separate regulation of long-distance transmission and local distribution networks. Further possible extensions include allowing non-vertically integrated energy producers and retailers to compete with vertically integrated energy firms, in which case wholesale price risk and possible wholesale price caps might be considered. Finally, the investment implications of how network regulation interacts with energy market activities could be considered, especially in light of policies for decarbonizing energy sectors. These extensions are left to future work.

References

[1] Bennett, M., 2002, *Dual Regulation or Duelling Regulators? The Welfare Impacts of Overlapping Regulatory Regimes*, Mimeo, University of Warwick.

[2] Borenstein, S., Bushnell, J. and S. Stoft, 2000, "The competitive effects of transmission capacity in a deregulated electricity industry", *RAND Journal of Economics*, 31(2), 294-325.

[3] Campbell, A., 2018, "Cap prices or cap revenues? The dilemma of electric utility networks", *Energy Economics*, 74, 802-812.

[4] Comnes, G., Stoft, S., Greene, N. and L. Hill, 1995, *Performance-Based Ratemaking for Electric Utilities: Review of Plans and Analysis of Economic and Resource-Planning Issues*, Volume I, University of California Berkeley Report, November.

[5] Contreras, J. and G. Gross, 2004, *Transmission Investment in Competitive Electricity Markets.*

[6] Crew, M. and P. Kleindorfer, 1996a, "Price Caps and Revenue Caps: Incentives and Disincentives for Efficiency", in Crew, M. (ed.), *Pricing and Regulatory Innovations Under Increasing Competition*, Kluwer Academic Publishers.

[7] Crew, M. and P. Kleindorfer, 1996b, "Incentive Regulation in the United Kingdom and the United States: Some Lessons", *Journal of Regulatory Economics*, 9, 211-225.

[8] Doni, N. and P. Mori, 2014, *Pricing and price regulation in a customer-owned monopoly*, Euricse Working Paper no. 70|14, September.

[9] Downward, A., Zakeri, G. and A. Philpott, 2010, "On Cournot Equilibria in Electricity Transmission Networks", *Operations Research*, 58(4), Part 2, July-August, 1194-1209.

[10] Giles, D. and N. Wyatt, 1993, "Economies of Scale in the New Zealand Electricity Distribution Industry", in Philips, P. (ed.), *Models, methods, and applications of econometrics*, Oxford Blackwell, 370-382.

[11] Harris, C., 2014, *Fixed and Variable Costs: Theory and Practice in Electricity*, Palgrave Macmillan.

[12] Heim, S., Krieger, B. and M. Liebensteiner, 2018, *Unbundling, Regulation and Pricing: Evidence from Electricity Distribution*, ZEW Discussion Paper No. 18-050, November.

[13] Joskow, P., 2008, "Incentive Regulation and Its Application to Electricity Networks", *Review of Network Economics*, 7(4), December, 547-560.

[14] Lantz, B., 2008, "Hybrid revenue caps and incentive regulation", *Energy Economics*, 30, 688-695.

[15] Meade, R. and M. Söderberg, 2020, "Is Welfare Higher when Utilities are Owned by Customers instead of Investors? Evidence from Electricity Distribution in New Zealand", *Energy Economics*, 86, February, 104700.

[16] NRECA, 2025, Electric Co-op Facts & Figures, `https://www.electric.coop/electric-cooperative-fact-sheet`.

[17] NRECA International, 2010, *Guides for Electric Cooperative Development and Rural Electrification.*

[18] Qasim, M., Rasmussen, K., Månsson, J., Månsson, K. and M. Söderberg, 2024, *A comparison of the efficiency scores of different ownership types of electricity distributors in the Nordic countries using robust matching methods*, unpublished manuscript, Jönköping International Business School.

[19] Sauma, E. and S. Oren, 2006, "Proactive Planning and Valuation of Transmission Investments in Restructured Electricity Markets", *Journal of Regulatory Economics*, 30, 261-290.

[20] Sappington, D. and D. Weisman, 2024, "40 Years of Incentive Regulation: What Have We Learned, and What Questions Remain?", *Review of Industrial Organization*, 65, 361-373.

[21] Yao, J., Oren, S. and I. Adler, 2008, "Modeling and computing two-settlement oligopolistic equilibrium in a congested electricity network", *Operations Research*, 56(1), 34-47.

[22] Yatchew, A., 2000, "Scale Economies in Electricity Distribution: A Semi-parametric Analysis", *Journal of Applied Economics*, 15, 187-210.

[23] Weisman, D., 2025, "On the incentive properties of revenue cap regulation", *Energy Economics*, 141, 108052.