# Price Reform in Kuwait's Electricity and Water Sector:

Assessing the Net Benefits in the Presence of Congestion
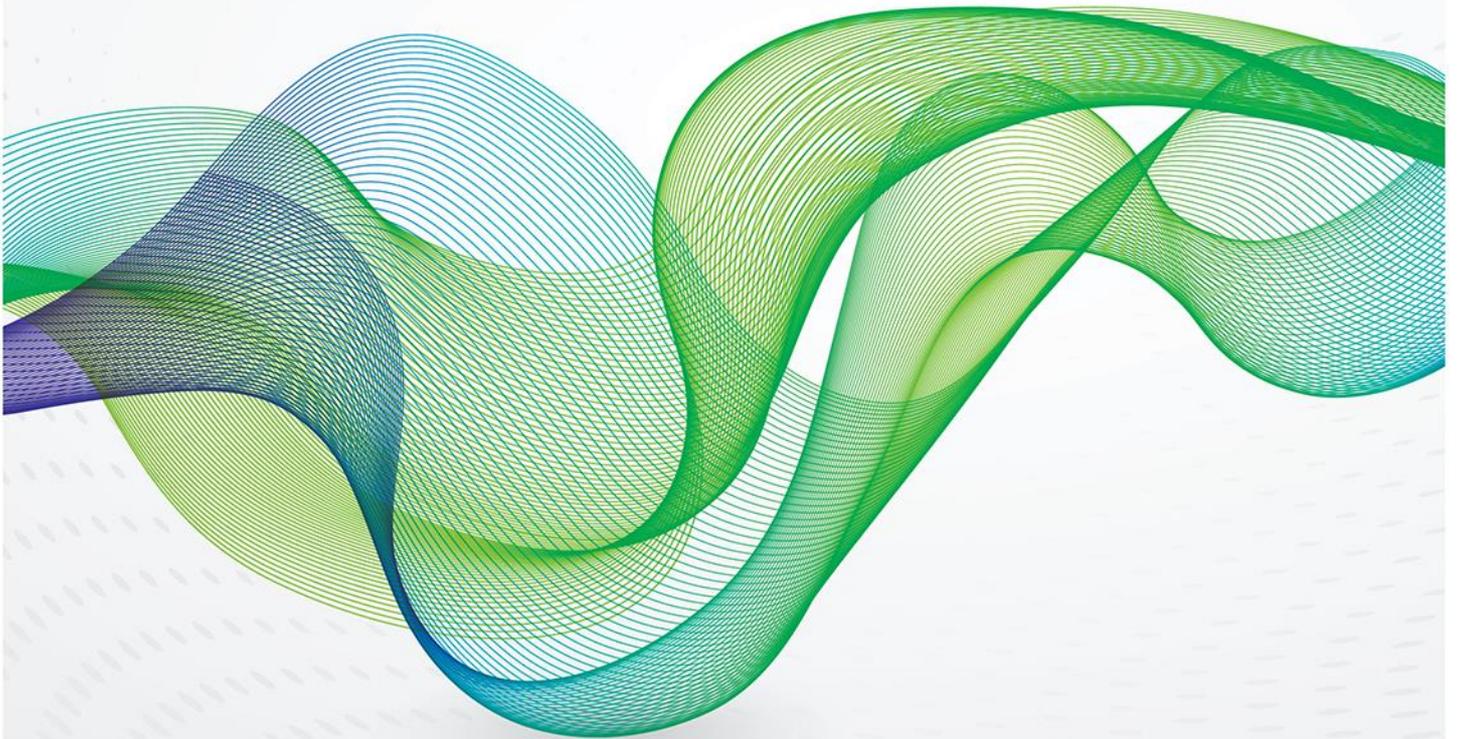
**Bassam Fattouh
and Lavan Mahadeva**

Oxford Institute for Energy Studies
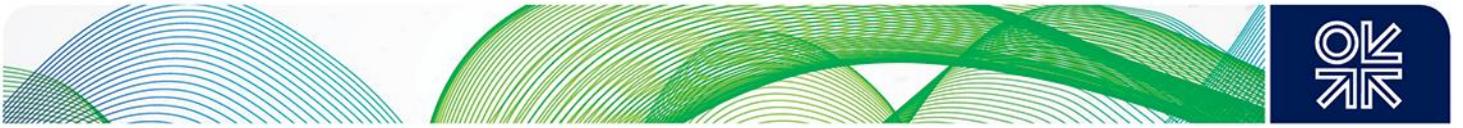
The contents of this paper are the authors' sole responsibility. They do not necessarily represent the views of the Oxford Institute for Energy Studies or any of its members.

Contents

Figures

Tables

Acknowledgements

1   Introduction

The 2010–14 Kuwait Development Plan envisages a massive increase in the scale of Kuwait's electricity and desalinated water co-generation. The centrepiece of the plan is the Al Zour gas-fired power and seawater treatment plant. When completed, this project will account for almost 12 per cent of Kuwait's power generation capacity and almost 25 per cent of desalination capacity. In addition, there are government plans to build a new refinery (the Al Zour refinery) with a capacity of 615,000 b/d; of this, 225,000 b/d will consist of low-sulphur fuel oil to meet the growing demand from the power sector. These massive infrastructure projects are aimed at bridging a widening gap in the demand and supply of Kuwait's electricity and water. According to the EIA (2013), Kuwait is already 'perpetually in a state of electricity supply shortage and experiences frequent blackouts and brownouts each summer'. Its desalinated water supply, representing about half of its total water supply in 2011 and most of its drinking and domestic water, is also expected to come under strain, even though capacity has been increasing on average by 4.1 per cent from 1992–2008 (Alotaibi, 2011). The shortfall in supply of these key services is even more striking given that Kuwait is among the world's most prosperous countries.

In this paper, we argue that Kuwait's power and desalinated water generation inadequacies are as much a consequence of the low prices charged for Kuwait's utilities as of the insufficiencies of its infrastructure. We use a model-based methodology to compare the current pricing scheme against an alternative where consumer prices are raised to market levels and consumers are on average compensated by cash transfers that do not distort their economic decisions. The model captures three important economic features of the production of electricity and water:

- The greatest share of production costs is taken by fuel – whose market price is unpredictable.
- The maximum supply in the short run is constrained by the existing level of infrastructure; when output is close to that limit, marginal costs rise sharply and the system becomes congested.
- The demand for these services is quite inelastic.

In our model, the electricity and water provider combines the three inputs of fuel, labour, and infrastructure to deliver these services to the consumer. We allow the infrastructure provider to be an independent profit maximizer whose decision to provide a level of infrastructure depends on the return they receive. As the market price is stochastic, we use nonlinear rational expectations Monte Carlo methods to solve for the optimal level of infrastructure, taking account of uncertainty. The model is simulated in two modes:

- the first reflects the current pattern of low pricing,
- the second captures a market price plus cash transfer scheme.
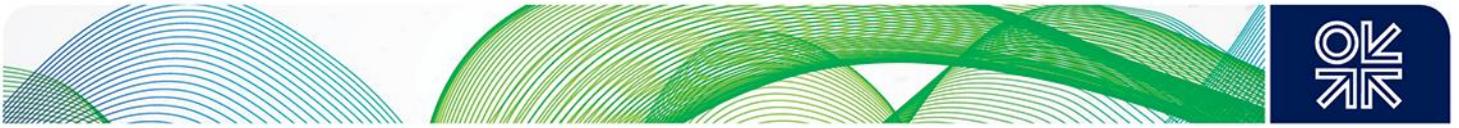
In the first mode, the government fixes a low price to the consumer. The producer has to receive a high enough price to ensure a sufficient rate of return. The difference between this high producer price and the low consumer price (multiplied by output) is a fiscal cost that is financed by the government. We experiment with three levels of fixed consumer prices: 10 per cent, 55 per cent, and 70 per cent of the average market price.

In contrast, in the second mode, consumers pay the unfettered market price. They are compensated on average for the utility-equivalent loss from moving to the market regime through the operation of a cash transfer scheme. The cash transfer schemes involves an alternative fiscal cost, which replaces the subsidy costs in the first mode. The net benefit of the second mode is the fiscal cost in the second mode minus the fiscal cost in the first mode.

Our main finding is that a realignment of prices at or closer to the market price level confers a benefit on current and future generations of Kuwaitis, in terms of fiscal savings, that outweighs the impact of raising electricity and water consumer prices to market price levels. Specifically, in the market price scenario with consumer prices at about ten times current levels, there is a total fiscal cost of about one-third of the value of fuel input used in the power sector (or about 1.5 per cent of GDP), entirely due to the cash transfer. This, however, is just less than one-fifth of the fiscal cost of the current low-price regime, and in principle represents a massive saving. The net benefit of moving to market prices is 140 per cent of the value of the fuel input, or 6.3 per cent of GDP. By implication, if it is judged that a cash transfer scheme, undifferentiated by usage, can help gain acceptance of this policy, it is shown to be affordable. We also show that the shift to market pricing will be a more efficient route to achieving spare capacity in the electricity and water system, rather than paying for additional infrastructure.

There are no other studies that seek to quantitatively extract estimates of these concepts to electricity and water. Certainly there are studies that model electricity generation and transmission and distribution networks in more detail than ours, and also allow for congestion. But few seek to calculate the net benefit of shifting away from the consumer regime and are calibrated for a GCC country like Kuwait.[1] The joint presence of two features of GCC countries – first that desalinated water is co-generated with electricity using fuel, and second, the severe extent of fiscal subsidies[2] – calls for a special design. There are studies that estimate the net benefit of moving away from a subsidy regime based entirely on static demand function, such as IMF (2012). We incorporate these calculations into

---

[1] Al-Qudsi and Al-Shatti (1987a) examine the viability of replacing existing residential electricity tariffs with lifeline rate structure and show that the lifeline rate structure is viable from the perspective of equity, conservation, and efficiency. Al-Qudsi and Al-Shatti (1987b) use a social welfare concept to assess the potential welfare losses resulting from electricity tariff restructuring across various classes of users.

[2] There are a few studies that usefully describe the problems and strains on Kuwait's power and water sector, for example: Alotaibi (2011), de Bouncourt (2012), and Fattouh and El-Katiri (2012). However, the calculation of the comparative costs of the regime requires analytical model-based methods.
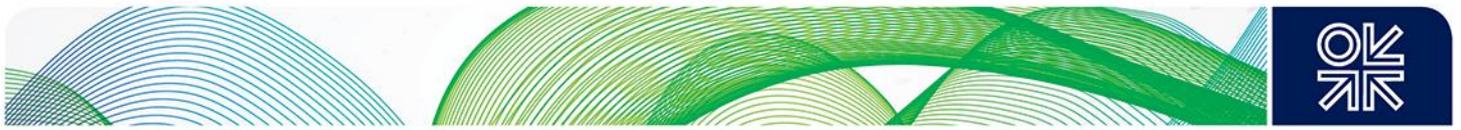
our work, but also show how a more complex model-based estimation, which brings in the possibility of congested supply, can improve on them. We also calculate the size of the cash transfer needed to compensate the average consumer, assuming all consumers are alike. We supplement this with a brief discussion of the main features and controversies concerning the design of a cash transfer mechanism.

The paper is structured as follows: Section 2 provides some summary statistics for the Kuwaiti economy while Section 3 explains aspects of the conceptual context of our work. In Section 3.1, the special features of power and water generation, a key feature of the model, are explained. In Section 3.2, we explain the static demand-based calculations that have been used previously in the literature to quantify the benefits of price reform. Section 4 explains our model. Section 5 explains and justifies our calibrations. Section 6 presents the design of our experiments and presents and discusses the results. Section 7 explains the cash transfer policy. Section 8 concludes and presents the caveats in our study.

2   Kuwait: Some Basic Facts

Table 1 presents some summary statistics for the Kuwaiti economy. As can be seen from Table 1, gross national saving as a percentage of GDP is relatively high, almost 60 per cent of GDP in 2011. Kuwait is an important oil producer with oil output of 2.66 million b/d and a total oil exports value of 96.7 US$ billion in 2011. Domestic oil consumption has been rising fast and exceeded 380 thousand b/d in 2011. Kuwait's electricity consumption per capita has exceeded 16,000 kwh, and is one of the highest in the world. (Electricity demand has been growing at an impressive rate estimated at an annual rate of 5.3% between 1999 and 2009 (de Boncourt, 2012). The power and water sector constitute the main source of domestic energy demand reaching 272.5 thousand boe/d of liquid fuels (fuel oil and diesel) and natural gas in 2009. Kuwait is the world's largest water consumer with water consumption per capita per day of 500 litres. Kuwait is a highly water-stressed country with the lowest level of renewable internal freshwater resources per capita in the world. According to KISR (2011), the current cost of providing a reliable source of fresh water in Kuwait (principally through desalination plants) exceeds 1.2 US$ billion annually. The government estimates that by the year 2050, given current consumption patterns, the majority of the country's revenue that is generated by oil will be required to fund the increased production of desalinated water.

Table 1: Kuwait: Some Basic Indicators

	2011	Source
Macroeconomic Indicators		
Nominal GDP (Market Prices, in billion of Kuwaiti Dinar)	44.3	IMF
Nominal GDP (Market Prices, in billion of US$)	160.7	IMF
Gross National Saving (% of GDP, Market Prices)	59.5	IMF
Investment (% of GDP, Market Prices)	16.4	IMF
Oil and Gas		
Total Oil and Gas Exports (billion of US$)	96.7	IMF
Average oil export price (US$/barrel)	103.3	IMF
Crude Oil Production (million b/d)	2.66	IMF
Total Domestic Petroleum Consumption (thousand b/d)	383	EIA
Power Sector		
Electric Power Consumption (kwh/capita)	16,122	World Bank
Electrity price for industry (US cents/Kwh)	0.35	Ministry of Electricity and Water; State of Kuwait
Electricity Produced (million kw/h)	57457	State of Kuwait, Central Statistical Bureau
Electricity Consumed (million kw/h)	50374	State of Kuwait, Central Statistical Bureau
Consumption by power and water sector (oil and gas, thousand boe/d)*	272.49	Minsitry of Oil, State of Kuwait
Water		
Renewable Internal Fresh Waters Resources per Capita (Cubic meter)	0	World Bank
Water consumption per capita per day (liters)	500	Kuwait Financial Centre
Price of water to state facilities & companies (US$/1000 gallon)	2.84	Ministry of Electricity and Water; State of Kuwait
Population		
Population	3065850	State of Kuwait, Central Statistical Bureau
Kuwaitis (%)	35.6	State of Kuwait, Central Statistical Bureau

* Data for 2009.

The strong unbridled demands for water and electricity are only in part a consequence of inevitable factors (such as population growth, urbanization, a falling average household size, and rising real income per head) they are also due to the artificially low consumer prices set by the government. The Kuwaiti government provides these basic utilities at a very low cost. Historically, the price of electricity had some links with the cost of production, but this link has been broken, and rather than raising electricity prices, the government has reduced them over time. In 1953, the selling price was 27
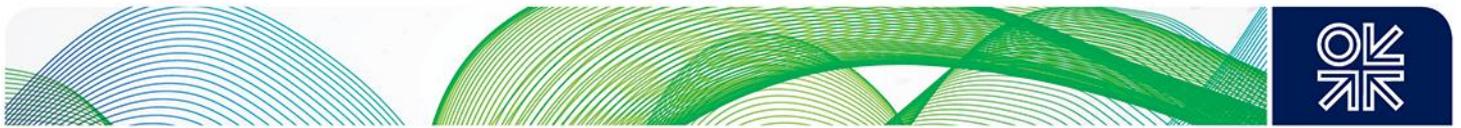
fils/kWh but between 1953 and 1955, when oil revenues start flowing into the state's coffers, the government decreased the selling price to 18 fils/kWh. The electricity tariff continued on its downward trend over the years until 1966 when the government set the price at 2 fils/kWh (0.7 US cents) for ordinary consumers and 1 fils/kWh (0.35 US cents) for industrial companies, very low even by regional standards. The 1966 tariff structure is still in force today, though for chalets/villas, the price of electricity has been raised to 10 fils/kwh (3.5 US cents).

Table 2: Development of Electricity Pricing in Kuwait

Period	Consumer Type, fils/kwh
Up to 30 September 1953	All consumers: 27
From 1/10/1953 to 31/3/1955	All consumer: 18
From 1/1/1961 to 30/4/1961	Up to 200 units, 7.5
	2000 to 4000 units: 6
	In excess of 4000 units: 4.5
From 1/5/1961 to 31/3/1964	Ordinary Consumers: 6
	Industrial and Agricultural Consumers, 4
From 1/4/1964 to 31/5/1965	Ordinary Consumers: 5
	Industrial and Agricultural Consumers, 4
From 1/6/1965 to 31/5/1966	Ordinary Consumers: 3
	Limited Income Groups: 2
From 1/6/1966	Ordinary Consumers: 2
	Industrial Companies: 1
Current Tariff	State facilities: 2
	Supported industrial companies: 1
	Chalets:10

Notes: 1 Kuwaiti Dinar Kuwait = 1000 fils. 1 Kuwaiti Dinar ≡ 3.55 US$
Source: Al-Qudsi and Al-Shatti (1987); Ministry of Electricity and Water; State of Kuwait.

Due to these low prices, there is a wide gap between production costs and the selling prices of electricity. In the early 1980s, the average cost of electricity production was estimated at 26 fils/kWh, while the price was administratively set at 1–2 fils/kWh (Al-Qudsi and Al-Shatti, 1987). The rise in oil prices in international markets in the mid 2000s, together with Kuwait's increasing reliance on LNG imports to fuel its power sector, meant that the gap continued to widen over the years, as shown in Figure 1 below.
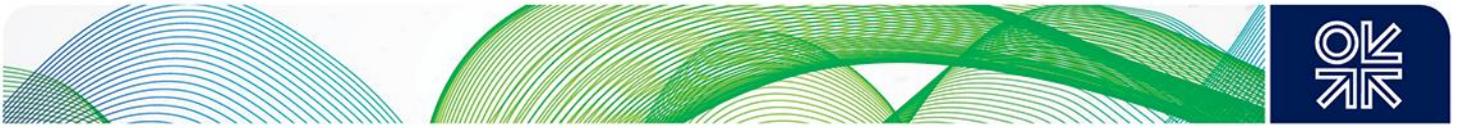
Figure 1: The Gap Between the Cost and Price of Electricity in Kuwait
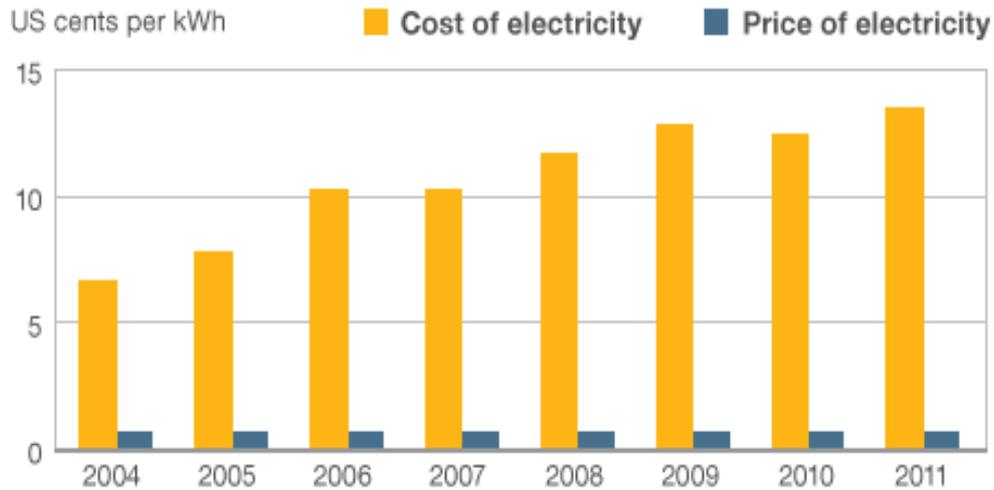
Source: 'Gulf States face hard economic truths about subsidies', BBC website 18 December 2012, based on Electricity Policy Research Group/State of Kuwait, Ministry of Electricity and Water.

Given the rapid increase in demand for electricity and water (de Boncourt, 2012), there is an urgent need for the Kuwaiti government to reconsider its low pricing policy for these basic utilities. The key to understanding our argument in favour of market prices is that higher prices serve to make consumers efficient in their use of energy. The promotion of efficiency in use through the use of appropriate prices is called *congestion pricing*. Congestion pricing can be contrasted to a *financially sustainable pricing* policy, where the main concern is whether the price charged is affordable by the ultimate financer of the investment. Given ample oil reserves and revenues in Kuwait, even very low prices for generated electricity can be fiscally sustainable. Hence it is the congestion price that is of concern rather than whether these prices can be afforded. As Nobel prize winner William Vickrey (Vickrey, 1963) explained, congestion pricing should dominate the financially sustainable price as the relevant concept whenever there is a public benefit from limiting individual usage: 'The delusion still persists that the primary role of pricing should always be that of financing the service rather than that of promoting economy in its use'. McCawley (2010) finds examples in Asia where the price of infrastructure (such as water services) in informal markets is much higher than in public markets, indicating that the public price does not cover the cost of congestion. Indeed, the social price for an activity should be subject to a surcharge above the private price so as to equate social marginal product to the social price.

The idea that congestion pricing can complement investment in infrastructure is also a theme in the economic literature. Gramlich (Gramlich, 1994), in his survey of the literature on infrastructure investment, shows that there any many definitions of infrastructure investment, but conceptually the definition that makes most sense refers to large capital-intensive monopolies, such as electricity and water. He goes on to argue that most studies have overwhelmingly focused on trying to ascertain the shortfall in infrastructure, as in the case of Kuwait, using either engineering, political voting, finance, or
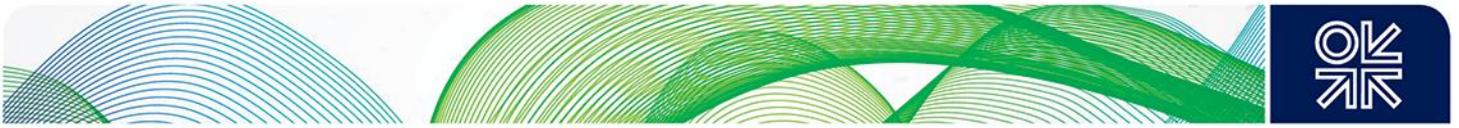
economic methodologies. Yet, he argues that a more relevant question concerns the role of government in the provision of infrastructure. He concludes by arguing that the greatest margin for improvement is in terms of user charges, taxation by willingness to pay, conservation charges for depreciation, as well as relieving congestion.

3   Concepts

There are two concepts that form the cornerstone of our analysis: the peculiarities of short-run supply in electricity and desalinated water, and the net benefit of market price reform as fiscal savings minus loss in consumer welfare. In this section, we explain these two concepts.

3.1   Short-run Marginal Cost of Power and Water: Congestion and Infrastructure

An important feature of the supply of electricity and desalinated water is that there is a physical limit beyond which it becomes highly costly to generate extra volumes of the service and that this limit is determined by a level of infrastructure that is fixed in the short run. One reason for this is simply that these industries are capital intensive and therefore their fixed costs are large and discrete. The very nature of power generation, distribution, and transmission networks requires that lumpy investments are needed each time the maximum capacity limit is to be extended. Similarly the expansion of desalinated water capacity involves the provision of expensive upstream desalination facilities, downstream infrastructure of transmission pipelines to bring water to consumers, irrigation systems in the agricultural sector, and storage for potable water generated (Missimer, Sinha, and Ghaffour, 2012). When these two utilities are associated in co-generation, ever greater costs are involved in making new investments (Darwish, 2001; Hamoda, 2001). Indeed, the lumpiness of investments in these sectors is part of the familiar justification for electricity and water to be provided by a natural monopoly.

There is, however, a more idiosyncratic reason why electricity generation is subject to a maximum constraint in the short run. Loop flows mean that electricity flowing between a generator and a customer moves through all lines connecting the two, not just along the shortest distance between the two points. When combined with other technological constraints, such as line thermal limits and voltage tolerances, the presence of loop flow means that the extra amount of electricity generated at peak load is uncertain or difficult to calculate precisely. It is not easy to allocate one-to-one to transmission lines and this depends on the network pattern (Hogan, 1992; Turvey, 2000). In the absence of capacity network charges, capacity has to be extended in large increments to minimize the risk of insufficient provision.
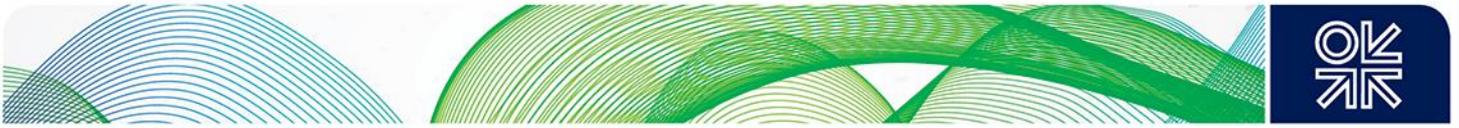
Figure 2 traces the form of a short-run supply curve with a maximum capacity limit, whose slope rises steeply as we approach the limit, with the cost of provision eventually becoming infinite at and above the hard constraint. Output levels just before and near to the capacity limit are called congested, where, as we explain later, there is a major risk of blackouts and rationing.

Figure 2: Short-Run Supply Curve of Electricity and Desalinated Water
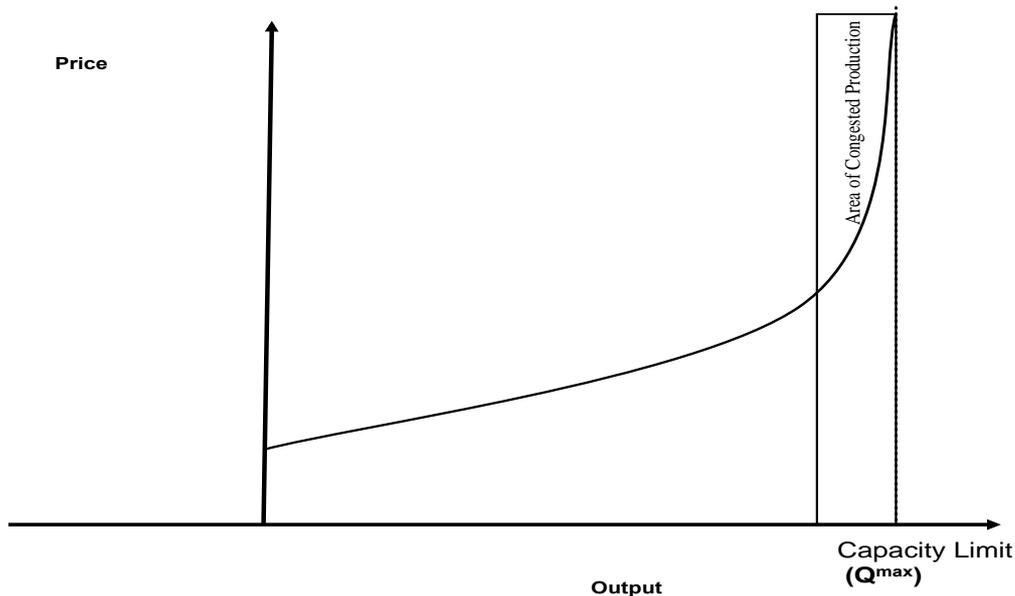
To emphasize this point further, Figure 3 compares the short-run supply curve of electricity and desalinated water (AB) to a standard short-run supply curve (AC) which has no limit. According to the standard supply curve, ever greater output can be secured even in the short run by raising prices by the same proportion. This situation is not a plausible description of the economics of supply of power and water. Stoft, in his textbook on power system economics (Stoft, 2002), discusses how a generation supply curve should have an extremely large but finite slope beyond a certain point. Deloittes (2013), for example, describe the 2010 power supply curve for the SERC Reliability Corporation (SERC) region that includes Louisiana, with a clear hard limit. Similarly, Agthe and Billings (2003), in their discussion of urban supply, emphasize that the short-run supply curve of water supply is best characterized as straightening up vertically at some point.

Figure 3: Short-Run Supply Curve of Electricity and Desalinated Water versus a Standard Supply Curve
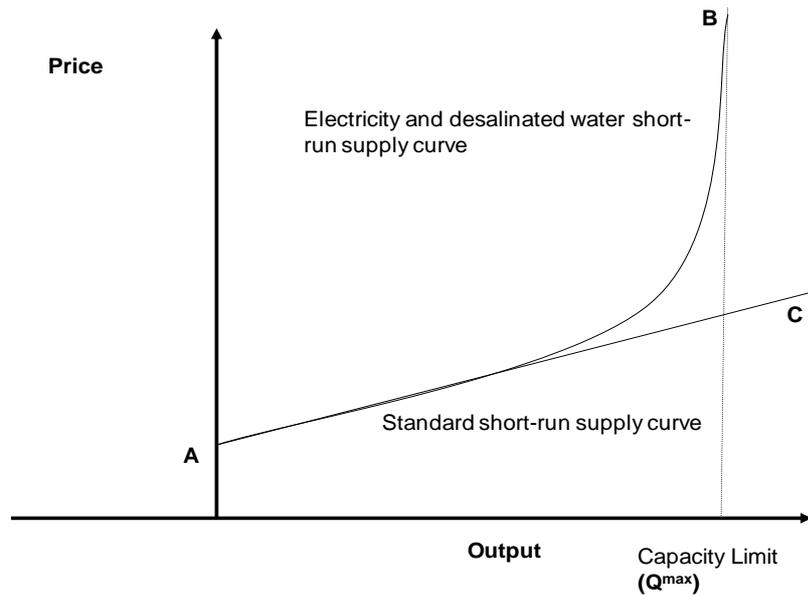
As these are short-run supply curves it is also true that, with time, this limit can be pushed back by installing additional infrastructure such that output is, on average, well below capacity. Figure 4 describes how a higher level of infrastructure shifts out the supply limit. Although it is true that most electricity and water generation plants, on average, run well below full capacity, it is also important to account for the installation and maintenance of the extra infrastructure needed. This means that there is a trade-off between extra capacity and profits. As we shall see below, that trade-off is made worse when consumer prices and profits are subsidized, as is the case in Kuwait.
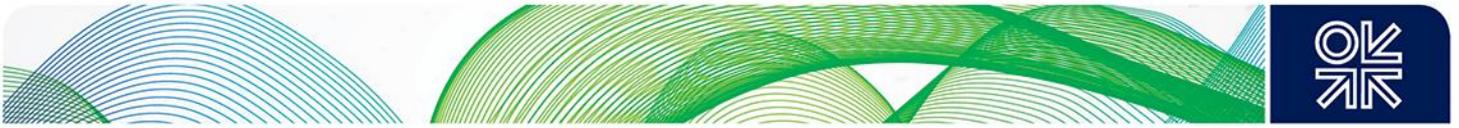
Figure 4: Short-Run Supply and Demand of Electricity and Desalinated Water with more Infrastructure
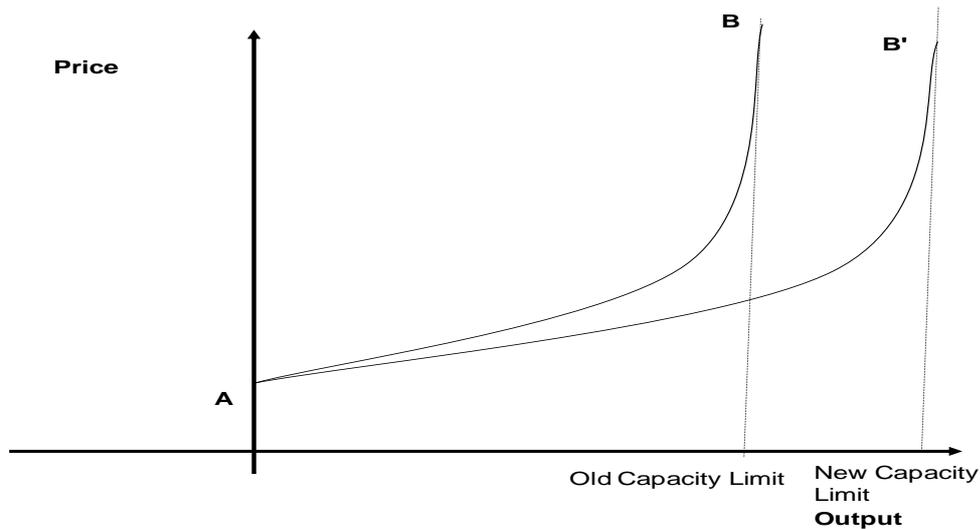
The reason why the particular shape of the supply curve of these services matters is that demand for electricity and water is highly uncertain. Power load fluctuates widely during a day, typically peaking during mid-afternoon and falling during the night. It also fluctuates across the year because of temperature changes, and these seasonal patterns are often of uncertain intensity. Uncertain seasonal fluctuations can be compounded by longer-run shifts that are also difficult to predict. In Kuwait, with its relatively fast-moving demographics, one such shift is the number of households, which determines the demand for power and water independently of population growth.

Figure 5 illustrates the problem. It describes how, when demand is already in the congested area, a further shift in demand from curve DD to D'D' pushes capacity to the limit.[3] In principle, the market price should rise very sharply. But in practice, large rapid market price movements are often avoided.

---

[3] The demand curve for water is shown not to have a constant slope in practice. In particular, the lowest levels of demand are more inelastic and there is a threshold below which demand is invariant to price. Allowing for this would, if anything, heighten the risk of congestion.
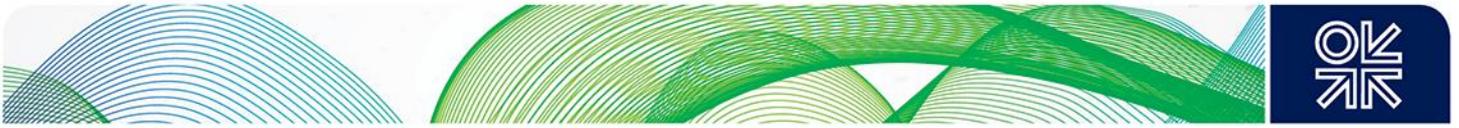
Figure 5: Market for Electricity and Desalinated Water with Shifting Demand
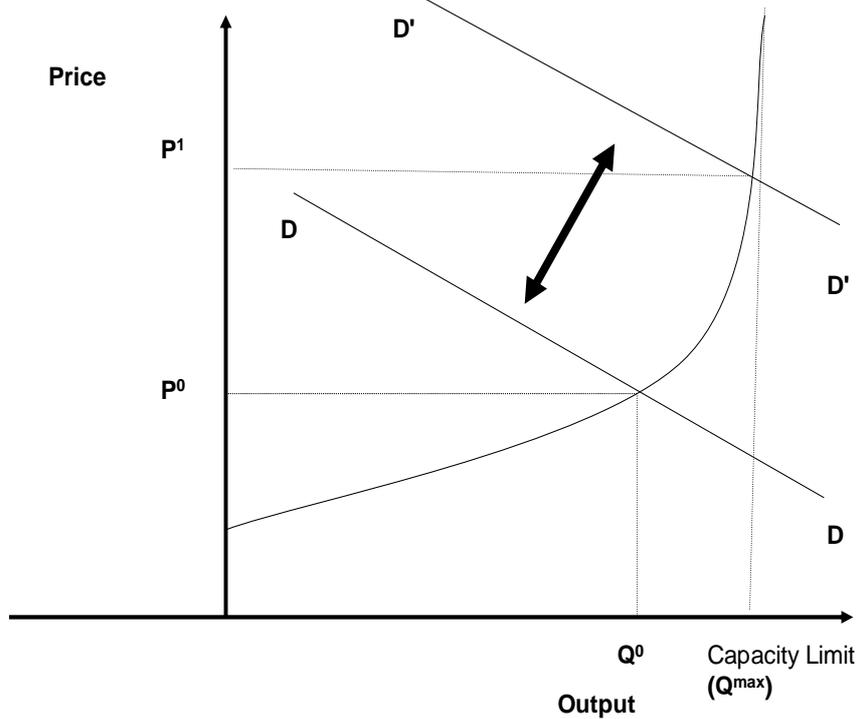
The presence of the infrastructure constraint, when combined with rigidities in short-run demand and a social consideration to guarantee the supply of key utilities without an abrupt rise in price, means that the market, left to operate by itself, will not ensure a socially acceptable outcome. Cramton and Ockenfels (2012) argue that the infrastructure constraint in power supply is a market failure, and a mechanism has to be at least fostered by the state to generate enough capacity in advance to guarantee sufficient supply when demand rises suddenly, as the risk of blackouts has to be kept at a socially acceptable level. Part of this mechanism is a higher producer price for electricity than otherwise, reflecting a capacity payment. This matters in the discussion of Kuwait's subsidized regime, because the extremely low consumer prices of power and water have clearly raised the risk of being in the congested zone to unacceptable levels. This also explains the continual demands for greater infrastructure spending.

Figure 6 compares various pricing policies for the provision of electricity and desalinated water:

- The first policy has a spot market price for existing capacity. This is where the supply curve AB crosses the demand curve DD: with prices at P^{c1} and volumes at Q^{c1}.

- The second policy is one where only the consumer price is set artificially low at P^{c2} (below the market price P^{c1}). With prices at this low level, demand at Q^{c2} is much higher than supply at Q^{p2}, and electricity and water must be rationed.

- A third policy aims at remedying this insufficient supply by also subsidizing a higher producer price and paying for extra capacity. The payment for extra capacity is sufficient to shift the curve out to
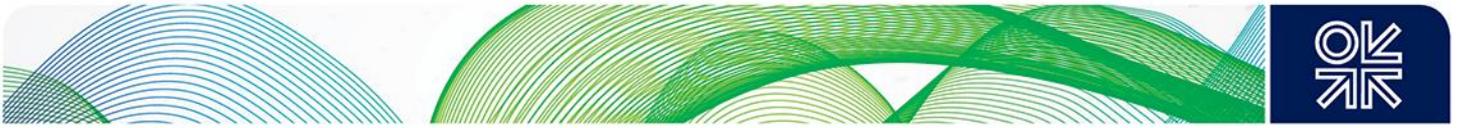
AB'. The higher producer price is P^{p3}, and the new level of supply matches demand at Q^{c2}. However, the increase in supply comes at the cost of two fiscal subsidies. First there is a payment for having the producer price above the consumer price, shown as a blue rectangle in Figure 6. Second there is a payment – the investment in greater capacity – which is not shown in the chart. This policy is the one that most closely describes Kuwait's current regime.

- A fourth policy allows for prices higher than the spot market price. In this case, the price level is P^{c4} and demand is Q^{c4}. The revenue generated by this higher price could be used to finance an investment in capacity, in which case full capacity supply is Q^{p4}. The substantial excess capacity provides a buffer against unexpected fluctuations. This is a capacity payment regime, with no fiscal costs.

Figure 6: Market for Electricity and Desalinated Water under Four Different Pricing Policies
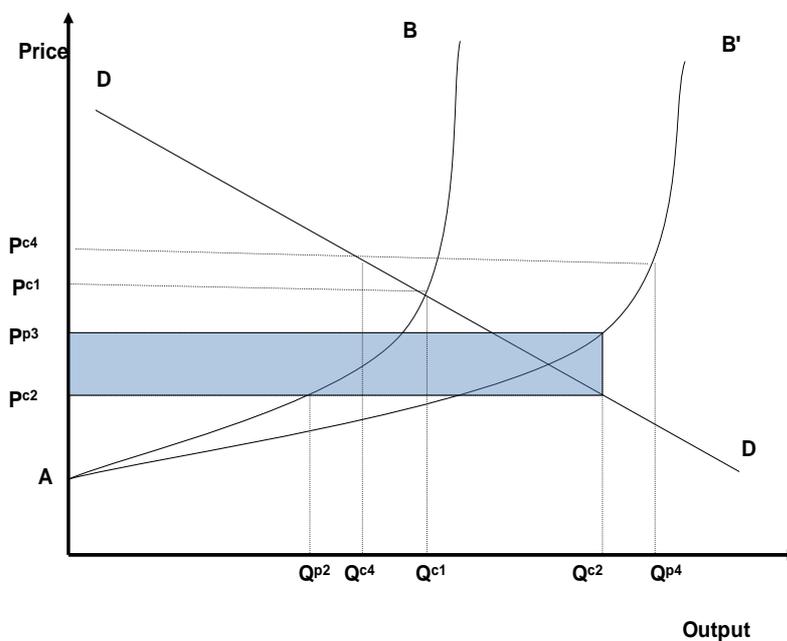
The main point that we highlight with the policy comparisons in Figure 6 is that a pricing policy is complementary to infrastructure investment in the provision of these key services, given the presence of a short-run limit. That said, the advantages of one regime against another should be judged not purely in terms of fiscal costs, but also by considering benefits to consumers. We proceed to do this in the rest of the paper.

3.2   The Net Benefit to Consumers: Static Demand-based Calculations

One of the main objectives of this paper is to calculate the net benefit to consumers of moving from a subsidy regime to a market-price regime in a model where the subsidized good is produced not purchased and the amount of infrastructure is determined endogenously. This improves on the
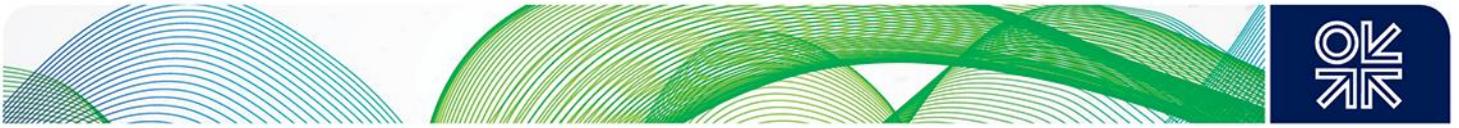
standard calculation of the net benefit which assumes that the subsidized good is purchased at market prices and that supply is elastic. In this section we describe that standard demand-based calculation.

Figure 7: Calculating the Net Benefit to Consumers of a Cash Subsidy Scheme: the Static Case
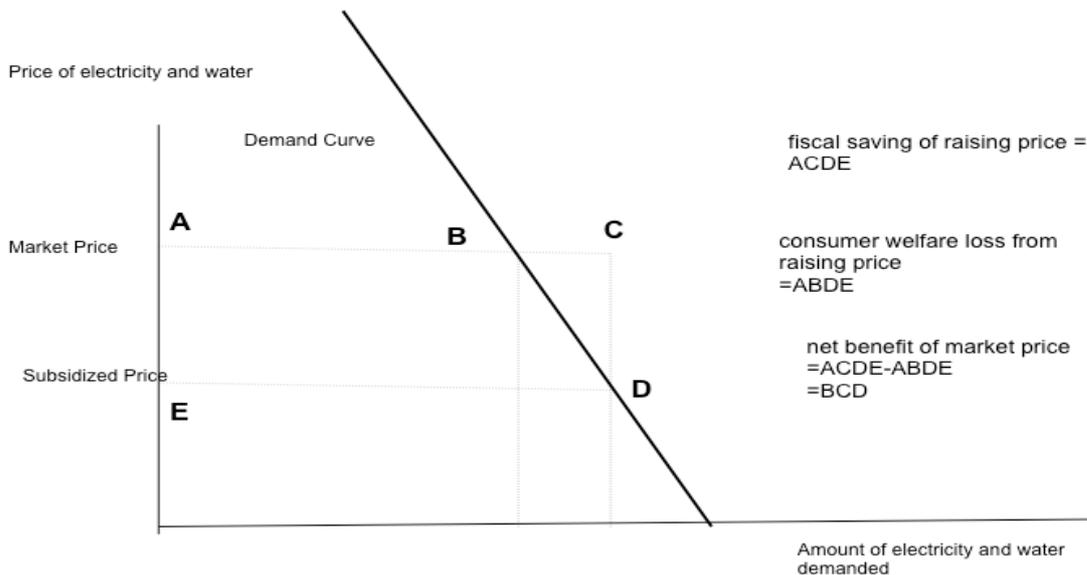
The calculation is based on comparing the revenue saved as a result of raising the price to the market price, to the consumer surplus lost by raising the price.[4] Figure 7 describes the demand curve. The revenue saved by raising the price from E to A, is the rectangle ACDE. The loss in consumer welfare from raising the price is the area under the demand curve, ABDE. Hence the net benefit is the area BCD. Clearly the size of the net benefit depends on the elasticity of the demand curve: the more elastic the curve, the greater the benefit. Naturally the lower the price below the market price, the greater is the net benefit.

But the demand-based calculation assumes that the good is purchased by the government is in elastic supply. More realistically, the government will have to pay producers a higher per unit price in order to enable them to satisfy the greater demand and still earn a sufficient rate of return. In the rest of this paper, calculations will be based on a more realistic model that allows for the fact that electricity is produced by a power generator and that infrastructure investment is needed to maintain capacity such that supply is not elastic.

---

[4] The calculation is (oppositely) analogous to the calculation of an optimal indirect tax, where the good most inelastically demanded should be taxed the most.
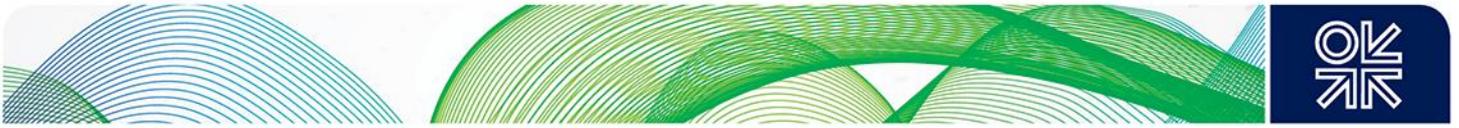
4   The Model

Our model of electricity and water desalination is designed to perform the essential task of describing the three main inputs into generation and highlighting the short-run constraint of a bottleneck. These services are generated by fuel, labour, and infrastructure. The intended generation capacity translates into actual generation after passing through a congestion function. Infrastructure differs from fuel and labour in that it relieves congestion.

Figure 8: A model of Electricity and Power Generation
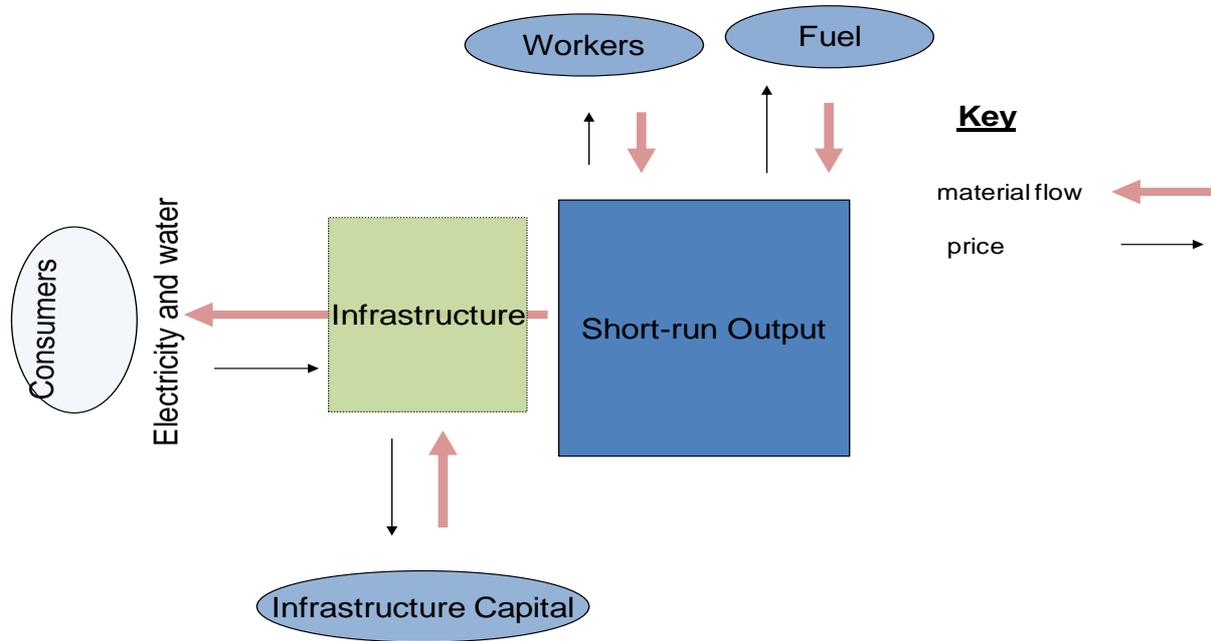
The most distinctive feature of our model is a production function of electricity and water, which allows for the level of infrastructure to determine final output, through loosening or tightening the constraints on short-run output. The flow of electricity and water (y_t) is a function of short-run output (o_t) and a bottleneck (z_t):

$$y_t = o_t(z_t)^\varepsilon \qquad (1)$$

where the size (or width) of the bottleneck depends on the ratio between private sector output (o_t) and infrastructure capital (x_t):

$$z_t \equiv \frac{x_t}{o_t + \omega x_t}. \qquad (2)$$

Short-run output is, in turn, a function of fuel (denoted by k_t) and labour (denoted by l_t), with fuel expected to take the lion's share of costs:
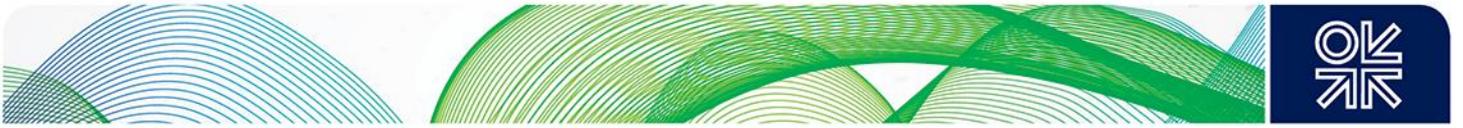
$$o_t = (k_t)^\alpha (l_t)^{1-\alpha} \tag{3}$$

with α representing the share in value of fuel in short-run output. The special nature of the production function and the bottleneck term introduced in equation (2) means that if short-run output is high relative to infrastructure, then the bottleneck tends towards zero and the total flow of electricity and water is constrained. On the contrary, if there is ample infrastructure relative to short-run output, then the bottleneck is wide. Hence the parameter (ε) represents the relative importance of the bottleneck, and hence infrastructure, in the determination of output.

The operation of the bottleneck also depends crucially on the value of a second parameter, (ω), which is responsible for an upward-sloping short-run supply function. To begin with, note that in equation 2, ω determines the ease with which each extra unit of infrastructure alleviates congestion in the bottleneck. In particular, a standard Cobb–Douglas production function can be recovered from (1) and (2) only when $\omega = 0$: $\omega = 0 \Rightarrow y_t = (o_t)^{1-\varepsilon}(x_t)^\varepsilon$, when infrastructure can be added with ease and is not lumpy.

To demonstrate the suitability of this particular function for the power and water generation problem, we can show that the maximum level of output flow that can be achieved in the short run is given by maximizing y_t with respect to o_t:

$$Max_{o_t}\, o_t \left(\frac{x_t}{o_t + \omega x_t}\right)^\varepsilon$$
$$\xrightarrow{yields} \hat{o}_t = x_t \left(\frac{\omega}{\varepsilon - 1}\right) \tag{4}$$
$$\text{and } \hat{y}_t = x_t \varepsilon \left(\frac{\varepsilon - 1}{\omega \varepsilon}\right)^{\varepsilon - 1}$$

According to (4), the maximum level of output ($\hat{y}_t$) is an increasing (linear) function of the level of infrastructure. Consistently, the bottleneck, z_t, will be constrained to fall in a range $\frac{\varepsilon - 1}{\varepsilon}\frac{1}{\omega} \leq z_t \leq \frac{1}{\omega}$, with the lower bound attained when output has hit its maximum bound. Note also that if ω were zero, and the production function standard, then the maximum level of short-run output would be infinite; in other words, there would be no finite upper limit and no short-run constraint, with ample infrastructure.

Let us denote the combined producer price of electricity and water by p_{yt} and the combined price of fuel and labour costs as p_{ot}. The short-run supply curve is found by solving the following problem:

$$Max_{o_t}\, p_{yt} y_t - p_{ot} o_t \text{ holding } x_t \text{ fixed.}$$
$$\Rightarrow Max_{o_t} \left(p_{yt} o_t \left(\frac{x_t}{o_t + \omega x_t}\right)^\varepsilon - p_{ot} o_t\right)$$
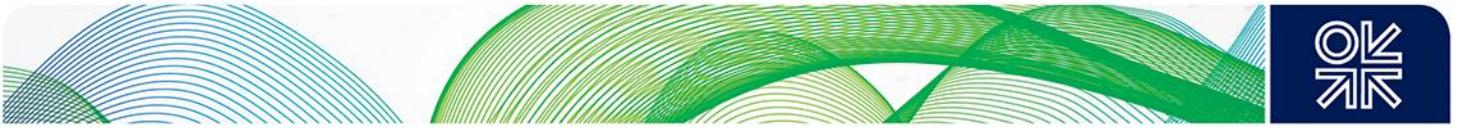
From the first-order conditions, and holding these prices and the level of infrastructure as constant, short-run supply is defined implicitly as the solution $y_t = f\left(x_t, \frac{p_{yt}}{p_{ot}}\right)$ to the set of equations:

$$
(z_t)^\varepsilon \left(1 - \varepsilon(1 - \omega z_t)\right) = \frac{p_{ot}}{p_{yt}}
$$
$$
\text{and } y_t = x_t (z_t)^\varepsilon \frac{1 - \omega z_t}{z_t} \tag{5}
$$
$$
\text{for } 0 \leq y_t \leq \hat{y}_t.
$$

Through comparing derivatives we can show that, as long as ω is positive, this supply curve will take the form described in Figure 2: its slope is flat at low levels of output but rises steeply to become vertical at the maximum short-run level of output. If ω were zero, then the production function and supply curve would be of the standard form, with a fixed slope, and hence unsuitable for modelling electricity and water supply. Following the arguments in Section 2, we would want ω to be positive and far above zero for a realistic description of power and water supply.

Uncertainty in costs matter for production costs. In the case of power generation, this is due to the massive uncertainties surrounding the fuel price. We allow for the logarithm of the market price of fuel to be determined by a stochastic process that is a discrete approximation to a mean-reverting Ito process:

$$
\ln(p_{k,t}) = \mu(1 - \rho) + \rho \ln(p_{k,t-1}) + \sigma \epsilon_t \tag{6}
$$

where μ is the long-run mean of the log of prices, while ρ captures the persistence in fuel prices and represents the standard deviation of annual surprises to the fuel price level. ϵ_t is generated from the Pearson family of distributions with mean zero, standard deviation 1, skew of –4, and kurtosis of 26. These values are designed to loosely match the empirical behaviour of real oil prices.

To confirm this, Figure 9 plots the range of values that the market price can typically take over future years, beginning at its mean of 100. Note that the most likely value lies above the mean, but the forecast distribution acknowledges the possibility that prices can fall as low as one-fifth of the current value.
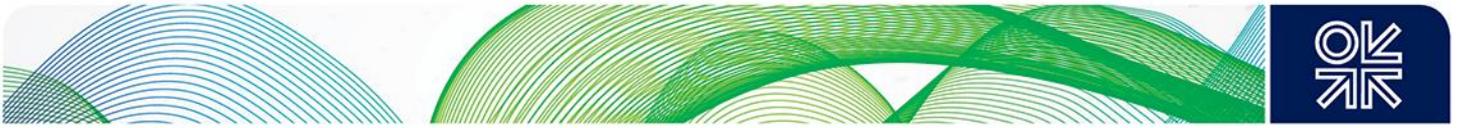
Figure 9: The Simulated Forecast Distribution of Fuel Prices
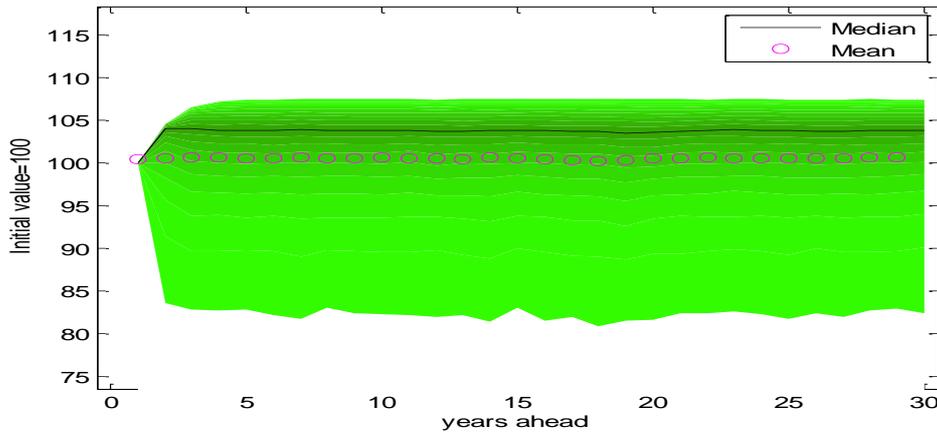
The markets for labour, fuel, and infrastructure are such that the prices of inputs ($p_{l,t}$, $p_{k,t}$, and $p_{x,t}$ respectively) equal their marginal revenue products, which depend on the producer price of electricity and water ($p_{y,t}$) as well as their physical marginal products:

$$p_{l,t} = p_{y,t}(1-\alpha)\frac{o_t}{l_t}(z_t)^\varepsilon\big(1-\varepsilon(1-\omega z_t)\big);$$
$$p_{k,t} = p_{y,t}\alpha\frac{o_t}{k_t}(z_t)^\varepsilon\big(1-\varepsilon(1-\omega z_t)\big); \tag{7}$$
$$\text{and } p_{x,t} = p_{y,t}\varepsilon\frac{o_t}{x_t}(z_t)^\varepsilon(1-\omega z_t),$$

with the bottleneck, z_t, defined as before:

$$z_t \equiv \frac{x_t}{o_t + \omega x_t} \ , \tag{8}$$

the amount of labour fixed at $\bar{l}$, the amount of fuel denoted by k_t, and the amount of infrastructure by x_t. Wages, ($p_{l,t}$), adjust perfectly to employ all labour, while fuel prices, $p_{k,t}$, are set exogenously by world market conditions.

The level of infrastructure is chosen to maximize the profits of the infrastructure, taking account of depreciation and investment adjustment costs:

$$Max_{x_t,\cdots,x_\infty} \sum_{s=t}^{\infty} \beta^s \frac{(\pi_s)^{1-\gamma}}{1-\gamma}$$
$$\pi_s = p_{x,s}x_s - c_0 x_s - i_s - \frac{\emptyset}{2}\left(\frac{i_s}{x_{s-1}} - \delta_x\right)^2 x_{s-1}; \tag{9}$$
$$\text{and } x_s = (1-\delta_x)x_{s-1} + i_s$$

Where c_0 is the cost of maintaining each unit of infrastructure, $\frac{\emptyset}{2}\left(\frac{i_s}{x_{s-1}} - \delta_x\right)^2$ captures the adjustment costs of investing in infrastructure, and δ_x is the rate of depreciation.
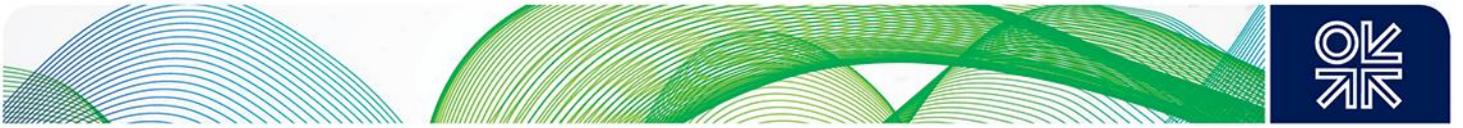
The consumer's utility function at any one moment in time is

$$U_{c,t} = \frac{\left(\varsigma y_t^{1-\xi} + (1-\zeta)\bar{d}^{1-\xi}\right)^{\frac{1-\gamma}{1-\xi}}}{1-\gamma} \qquad (10)$$

with y_t being the volume of electricity and water, $\bar{d}$, being the fixed volume of all other consumption, ς, being the share parameter, and ξ the important elasticity of demand for electricity. Total real consumption is $\left(\varsigma y_t^{1-\xi} + (1-\zeta)\bar{d}^{1-\xi}\right)^{\frac{1}{1-\xi}}$. The budget of the consumer is divided between electricity and water and all other items ($p_{c,t}y_t + \bar{d}$) with $p_{c,t}$ being the consumer price of electricity in terms of the price of the other items, which is the numeraire for all prices in the paper.

Hence, at any moment in time, the demand function for electricity and water is given consistently as:

$$\widetilde{p_{c,t}} = \frac{\varsigma}{1-\varsigma}\left(\frac{y_t}{\bar{d}}\right)^{-\xi}. \qquad (11)$$

When we consider consumer welfare, looking ahead into the future, it is natural to measure this with the expected discounted sum of these utilities:

$$W_t = E_t \sum_{s=t}^{\infty} \beta^{s-t} U_{c,s}. \qquad (12)$$

The model solves under two modes, driven by differences in pricing policy. In the subsidy regime, the consumer price of electricity and water is fixed at a predetermined ratio of their average consumer market prices ($\widetilde{p_{ct}} = \chi E[p_{c,t}]$). We experiment with three levels: first with consumer prices fixed at about 10 per cent of the average market price ($\chi = 0.1$), second with consumer prices at about 55 per cent ($\chi = 0.55$), and third with consumer prices fixed at 70 per cent ($\chi = 0.7$). To help achieve this, the producer price is set in each case for the infrastructure provider to earn an adequate net rate of return ($p_{x,t} - c_0$), such that the level of electricity and water produced is enough to match consumer demand at its artificially low price.

The cost to the government in the subsidy regime is equal to the difference between the producer and consumer price multiplied by the amount of power and water sold:
$$\left((p_{y,t} - \chi E[p_{c,t}])y_t\right).$$

In contrast, in the market price mode, the consumer price is free to move with supply and demand and the producer price is equal to the consumer price. All these prices vary with fuel price fluctuations, although consumer prices of water and electricity move less than one-to-one with fuel prices, reflecting the providers' natural ability to absorb variations in one component of costs with prices and quantities of other inputs.
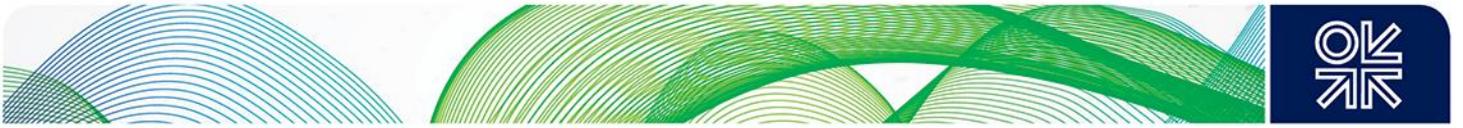
The only fiscal costs in the market regime are cash transfers. These are a stream of payments made by the government as a proportion of consumption determined in such a way that the consumer will be as well off as in the lowest price subsidy regime. To calculate their value, we solve for welfare in the lowest price subsidy regime (where $\chi = 0.1$) as:

$$W_t^{sub,\chi=0.1} = E_t \sum_{s=t}^{\infty} \beta^{s-t} U_{c,s}. \tag{13}$$

Consumption in the market regime is raised by a certain fixed proportion (λ) each period so that the average consumer's welfare in the market regime matches their welfare in the subsidy regime:

$$W_t^{sub,\chi=0.1} = (1+\lambda)^{1-\gamma} E_t \sum_{s=t}^{\infty} \beta^{s-t} \left(\varsigma y_t^{1-\xi} + (1-\zeta)\bar{d}^{1-\xi}\right)^{\frac{1-\gamma}{1-\xi}}$$
$$\Rightarrow W_t^{sub,\chi=0.1} = \lambda^{1-\gamma} W_t. \tag{14}$$

Hence the cash transfer as a proportion of consumption each period is given by:

$$\lambda \approx \frac{\left(\ln W_t^{sub,\chi=0.1} - \ln W_t\right)}{1-\gamma}. \tag{15}$$

Thus the net present value of the cash transfers stream paid by the government is:

$$\lambda E_t \sum_{s=t}^{\infty} \beta^{s-t} \left(\varsigma y_t^{1-\xi} + (1-\zeta)\bar{d}^{1-\xi}\right)^{\frac{1}{1-\xi}} \tag{16}$$

This is the only fiscal cost of the market price scenario.

By comparing the fiscal costs across the scenarios, we are able to assess the net benefit of the market price plus cash transfer scheme. An identical comparison can be made with any other scenario and the actual subsidy regime. The main technical difficulty in carrying out this type of analysis involves incorporating the effects of the stochastic fluctuations in the market fuel price on the infrastructure providers' decision. As infrastructure investments are planned over a long horizon, and the infrastructure provider is not risk neutral, the variance and riskiness of returns should matter.

When uncertainty plays a role, the decision on how much to invest depends on expected returns and risks, and the model has to be solved using a nonlinear rational expectations algorithm. In Appendix 1, we derive the necessary equations that fully describe the model and outline the numerical solution method. The solution method relies on Monte Carlo simulations: simulating for 10,000 stochastic price paths and estimating the infrastructure rule that best satisfies the expectation of discounted utility of infrastructure providers receiving a stream of uncertain profits. The solution also involves numerical optimization, using a pattern search algorithm. As a direct search method, it is derivative free and hence a good candidate for non-continuous, multimodal, and non-differentiable problems of this sort.
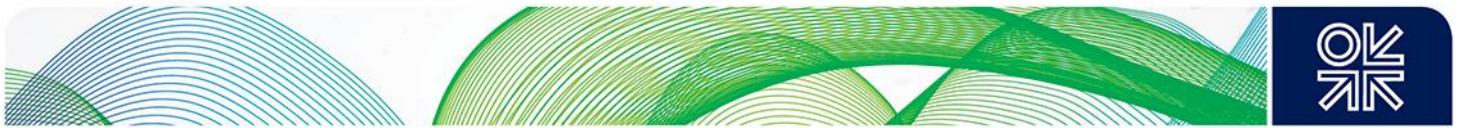
For example, Alsumiat, Sykulski, and Alothman (2007) advocate the pattern search method for the canonical Economic Load Dispatch Problem in electricity.

5 The Calibrations

The plausibility of our results depends on how well the model parameters match Kuwait's electricity market. Table 2 reports the parameter values chosen and the main stylized fact that this value was aimed at matching. The matching of parameters to stylized facts is not strictly one-to-one as the model is solved simultaneously, but associating a parameter with the main stylized fact is a more intuitive way of explaining the calibration. It is also important to remember that we match the model in the subsidy mode, as this best describes the Kuwaiti data.

Table 3: Calibrations of Model

Parameter	Explanation	Calibrated Value	Stylized Fact Chosen to Match	Source
ω	This parameter determines how much each extra unit of infrastructure in place alleviates congestion; it can lie in the range $[0, \infty]$	100	A high capacity factor in Kuwait's electricity in 2011 (60%).	EIA (2013)'s value of 46% for Kuwait seemed too low to us when compared to the USA (EIA, 2011) and given Kuwait's blackouts.
ε	This parameter determines how much infrastructure matters to production; it can lie in the range $[1, \infty]$	1.1	The chosen value implies that infrastructure takes 43% of total costs.	Christensen and Greene (1976)
α	This is exactly equal to the share of fuel in the short-run costs; it can lie in the range $[0,1]$	0.9	90% share of fuel in short-run costs of electricity.	Christensen and Greene (1976)
δ_x	The depreciation rate in infrastructure; it can lie in the range $[0,1]$	2.5%	Depreciation rates on electricity and water physical infrastructure.	United States Bureau of Economic Analysis (2004)
ϕ	This determines the ease with which infrastructure can be adjusted; it can lie in the range $[0, \infty]$	5	Ten times the typical investment adjustment cost parameter for industry, reflecting lumpiness.	Groth and Kahn (2010)
c_0	These are the recurrent costs of maintenance; they fall in the range $[0, \infty]$	0.59	Chosen to put the social rate of return on infrastructure at 15%, close to the average economic rate of return	(Canning and Bennathan, 2000)

			for World Bank projects (evaluated over the period 1983–92) of 11% for electricity projects.	
ζ	[0,1]	0.00002	The parameter value is set so that the share of water and electricity supply expenditure in consumption expenditure is 0.35. Data for 2007 shows that the share in Kuwait lay in between 0.3–0.4% in 2007.	Kuwait Central Statistical Bureau (2014)
ξ	This parameter is the inverse of the price elasticity of demand; in principle it can lie in the range[0, ∞]	1/0.5	Price elasticity of demand for electricity: Kuwait, -0.3 or -0.5, (fuel oil, -0.62); USA, (median –0.28). Price elasticity demand for water: Kuwait; (-0.77); USA: (-0.26 to -0.5).	Electricity, Kuwait: IMF (2012) and Bhattacharyya and Blake (2009) for fuel oil; USA: Espey and Espey (2004). Water, Kuwait: Milutinovic, Murtaugh and Eltahir (2006); USA: Espey, Espey, and Shaw (1997)
γ	This is the intertemporal elasticity of substitution; it lies in the range [1, ∞]	3	Chosen to allow substantial risk aversion and also to imply a social rate of return of 13% in conjunction with the inter-temporal rate of discount and a long-run per capita growth rate of 4%.	
β	This is the intertemporal rate of discount; in principle it lies in the range [0,1]	0.98 (2%)	Standard value use in many policy exercises.	
$\bar{d}$, $\bar{l}$	These are the base volumes of other consumption items and labour supply.	1	Normalized	

The most encouraging aspect of our calibrations is that we can only match as a high a capacity factor as we think holds for Kuwait's power and water generation (about 60 per cent) with a high value of ω, 100, far away from the standard Cobb-Douglas production function. Given a suitable value for this parameter, the calibrations of the other parameters of production (ε and α) follow from matching shares of costs by input to estimated data values:
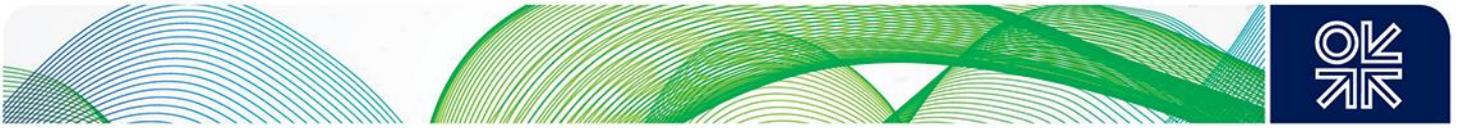
$$\frac{p_{l,t}l_t}{p_{y,t}y_t} = (1-\alpha)\big(1-\varepsilon(1-\omega z_t)\big);$$

$$\frac{\tilde{p}_{k,t}k_t}{p_{y,t}y_t} = \alpha\big(1-\varepsilon(1-\omega z_t)\big);$$

$$\text{and } \frac{p_{x,t}x_t}{p_{y,t}y_t} = \varepsilon(1-\omega z_t).$$

In this sense, the Cobb-Douglas specification is rejected by the data.

The investment costs of adding infrastructure were set to match acceptable values for depreciation and a rate of return which would be normal for other countries. However, we did naturally allow for much more lumpiness in investment than is normal in manufacturing. The parameters of demand were set in such a way that in the regime which best describes Kuwait currently, the share of electricity and water would be around 0.3–0.4 per cent, as in the CPI weights. The crucial parameter, the elasticity of demand, was chosen to approximate an average for electricity and water, as shown in the table. Finally the parameters that describe inter-temporal consumers were chosen to fit to standard values in the literature, but also to allow for a sufficiently high social rate of return on infrastructure, together with substantial risk aversion.

6   Experiments and Results

Our results are a comparison across four scenarios, summarized in Table 3. The first three scenarios are all variations on the subsidy scheme, each having a price fixed at a different percentage of the average of the varying market price. In the first subsidy mode, electricity and water consumer prices are fixed at about one-tenth of the market price; in the second subsidy scenario, they are fixed at about 55 per cent of the market price; and in the third subsidy scenario they are fixed at 70 per cent of the market price. According to de Boncourt (2012), electricity sales in Kuwait 'cover a little less than one-tenth of the power price, especially as payments are poorly enforced, and so do not even cover fuel costs'. Hence the first scenario is a good approximation of the current regime. A fourth scenario is the market price plus cash transfer scheme, with consumer prices allowed to vary to clear the market. Across the last three scenarios, the government pays a cash transfer to leave consumers as well off as in the first scenario.
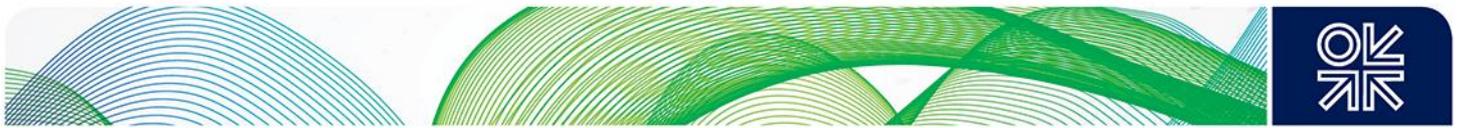
Table 4: Summary of Scenarios

Scenario	Mode	Consumer Price as a Percentage of Average Market Price	Fiscal Costs
1	Subsidized Price	About 10%	Electricity and Water Provider Subsidy
2	Subsidized Price	About 55%	Electricity and Water Provider Subsidy, Cash Transfer to keep consumer welfare at scenario 1.
3	Subsidized Price	About 70%	Electricity and Water Provider Subsidy, Cash Transfer to keep consumer welfare at scenario 1.
4	Market Price	Variable, on average 100%	Cash Transfer to keep consumer welfare at scenario 1.

Having laid out the model, explained its solution, and justified its calibration, we now proceed to describe the results. The relative differences in price levels are laid out in Figure 10. The relative levels of consumer prices (roughly 10 per cent, 55 per cent, and 70 per cent in scenarios 1, 2, and 3) reflect the assumptions in Table 3.

The implication for producer prices of electricity and water in Figure 10 are an outcome of the Monte Carlo simulations rather than an assumption. In the market price scenario, consumer and producer prices are equal, and there is no fiscal subsidy for producers. However, the producer prices in the subsidized price scenarios are all above consumer price levels. Indeed, they are estimated to be higher than the producer price in the market price regime (in scenario 4), at 129 per cent, 135 per cent, and 136 per cent respectively of the market price level. Producer prices need to be higher than otherwise when consumer prices are fixed at low levels, because producers require more compensation per unit to compensate for their losses resulting from operating at an inefficiently higher level of production. Though producers can, to some extent, alter wages and infrastructure demands into order to compensate for price differences, the distortion created by the need to supply a much larger subsidized demand in the face of fluctuating fuel input prices implies higher-than-otherwise producer prices. This is a natural consequence of having a less than perfect elastic supply for the subsidized consumer good. In summary, lower consumer prices imply higher than otherwise producer prices.
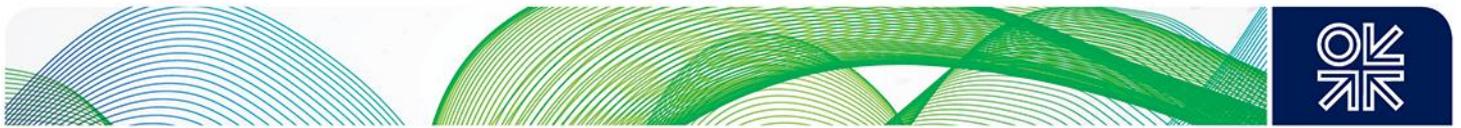
Figure 10: Differences in Price Levels Across Scenarios

	Scenario 1: Fixed at 10% of market price average	Scenario 2: Fixed at 55% of market price average (with compensating subsidy)	Scenario 3: Fixed at 70% of market price average (with compensating subsidy)	Scenario 4: Market Price (with compensating subsidy)
■ Consumer Price in Scenario (% of Market Price)	9.3	55.8	69.7	100.0
■ Actual Producer Price in Scenario (% of Market Price)	128.9	134.7	135.6	100.0

Figure 11 describes and breaks down the fiscal costs of each scenario. The most striking result is that the total fiscal cost in scenario 1 is 173 per cent of the value of the fuel input. De Boncourt (2012) calculates that fuel inputs were about 2 billion Kuwaiti dinars in 2011 or about 4.5 per cent of GDP, which we assume is priced at market prices. Hence the fiscal cost is about 7.7 per cent of GDP, being 173 times the share of fuel input in GDP, 0.045. As high as this might seem, it compares well with the IMF's estimate of 5.3 per cent of GDP for the actual cost of electricity and water subsidies in Kuwait in 2011 (IMF, 2011, Table 18). Scenario 2, illustrating an intermediate level of subsidy, envisages consumer electricity and water prices being five to six times higher than in Kuwait's current price regime, and has a total fiscal cost of just over half the value of the fuel input, whilst leaving consumers on average as well off as otherwise through a cash transfer. Scenario 3, which illustrates consumer prices raised to seven times the current low levels while still being held fixed, has a total fiscal cost of 40 per cent of the value of fuel input. Scenarios 2 and 3 reveal that as the fixed level of consumer prices rises, costs initially fall dramatically and then decline slowly. This is in part due to the additional fiscal cost of supporting producers in the face of fuel price uncertainty, taking the rigidities in short-run supply and the costs in adjusting infrastructure into account.

The market price scenario (scenario 4), with consumer and fuel input prices at about ten times current levels, has a total fiscal cost of about one-third of the value of fuel input (or about 1.5 per cent of GDP), entirely due to the cash transfer. This is just less than one-fifth of the fiscal cost of the current regime and in principle represents a massive saving. The net benefit of moving to market prices is 140 per cent of the value of the fuel input (= 173 – 32.2), or 6.3 per cent of GDP, a considerable sum. As a crude comparison, the IMF (IMF, 2012) calculates that the net benefit of removing subsidies on the gasoline price (raising that price by 183 per cent) is about 5.6 per cent of GDP in Kuwait, taking a
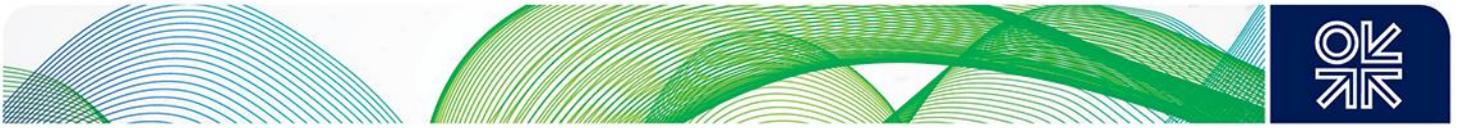
budgetary cost saving of 7 per cent and subtracting a consumer benefit loss of 1.4 per cent. Though this calculation relates to gasoline prices, which have a larger share in consumption, and it is not clear what they assume about elasticities of supply and demand, the comparison shows that our calculation implies a comparable estimate of the net benefit of price reform.

Figure 11: Differences in Fiscal Costs across Scenarios

	Scenario 1: Fixed at 10% of market price average	Scenario 2: Fixed at 55% of market price average (with compensating subsidy)	Scenario 3: Fixed at 70% of market price average (with compensating subsidy)	Scenario 4: Market Price (with compensating subsidy)
Fiscal cost of compensating consumers on average for removal of subsidies	0.0	20.5	25.0	32.2
Fiscal cost of subsidising consumer	172.6	31.9	15.6	0.0
Total fiscal cost	172.6	52.4	40.6	32.2

The cash transfers are designed so that consumers are, on average, equally well off in all regimes. In practice this means that the combined share of electricity and water and subsidy in the average consumption budget is the same. In Figure 12 we calculate the budget share of these utility services and subtract the cash transfer from that cost. We can see that as the consumer price increases tenfold, the share of electricity and water in the budget increases from 0.3 per cent to 0.9 per cent (or roughly threefold) still keeping below 1 per cent of consumption. The effect of the higher prices is to lower the amount of electricity and water consumed, offsetting higher prices to some extent. Once we take account of the mitigating cash transfer, the net share rises by only 0.1 pp, a small increase. Hence the cash transfer roughly offsets the effect of the higher prices on the average consumer's budget.
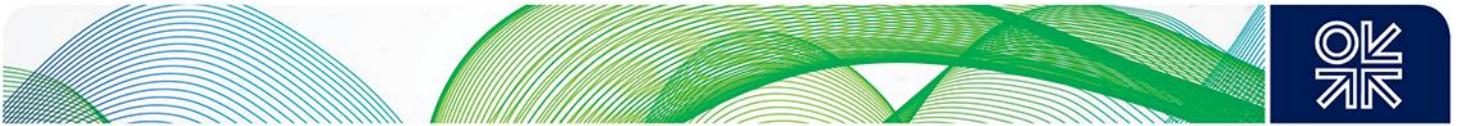
Figure 12: Net Electricity and Water Costs as a Share of Total Consumption

	Scenario 1: Fixed at 10% of market price average	Scenario 2: Fixed at 55% of market price average (with compensating subsidy)	Scenario 3: Fixed at 70% of market price average (with compensating subsidy)	Scenario 4: Market Price (with compensating subsidy)
■ Electricity and water costs	0.29	0.68	0.77	0.92
■ Minus Subsidy to Consumer	0.00	-0.39	-0.48	-0.62
— Net Share of Budget	0.29	0.29	0.29	0.30

It is important to recognize that a subsidized price regime also has implications for the relative shares of input costs between fuel, infrastructure, and labour. Figure 13 describes how, in the lowest price subsidy regime, almost 50 per cent of costs are taken up by infrastructure while in the full market-price regime this figure is 38 per cent. Clearly there is less need for infrastructure when consumers are sharing some of the burden of efficiency. It is in this sense that congestion pricing is a complement to infrastructure.

Figure 13: Inputs' Share of Total Electricity and Water Costs

	Scenario 1: Fixed at 10% of market price average	Scenario 2: Fixed at 55% of market price average (with compensating subsidy)	Scenario 3: Fixed at 70% of market price average (with compensating subsidy)	Scenario 4: Market Price (with compensating subsidy)
■ Fuel	45.3	46.3	46.4	55.8
■ Infrastructure (amortized)	49.7	48.6	48.4	38.0
■ Labour overheads	5.0	5.1	5.2	6.2
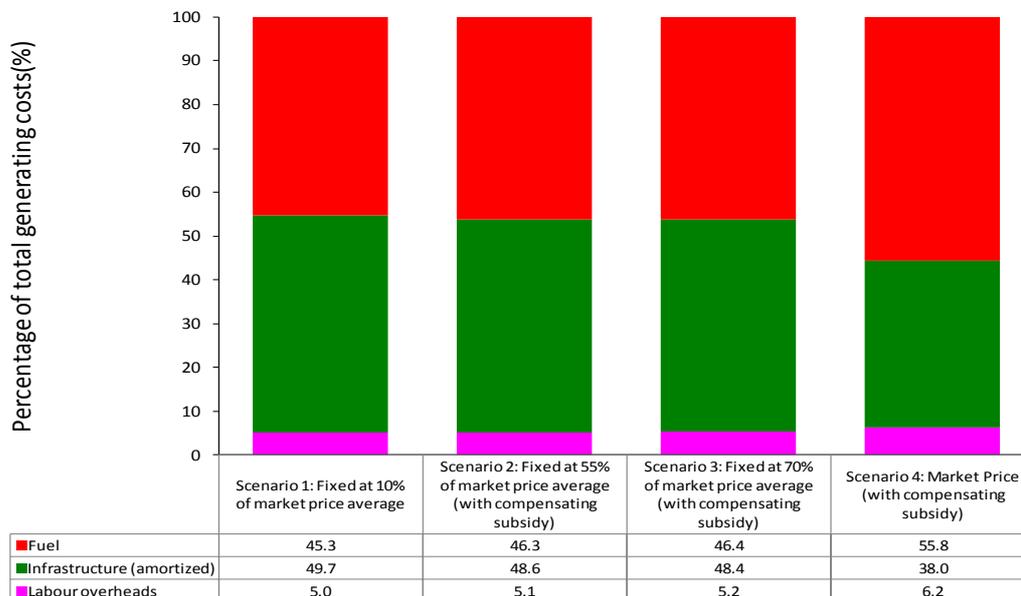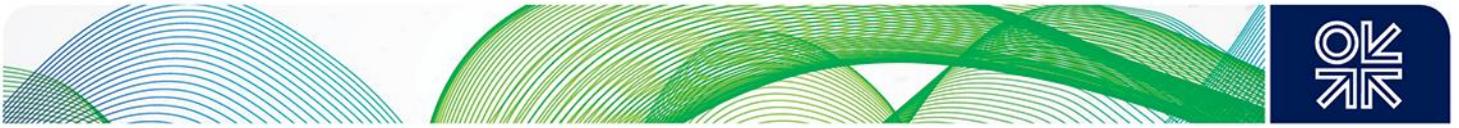
The effect of raising consumer prices tenfold and allowing them to fluctuate is naturally to encourage much greater efficiency in use. Ignoring the supply side of the model, and assuming an elasticity of demand of 0.5, the volume demanded of any good should fall to one-third of its current level as a result a tenfold rise in price (=$10^{\wedge}(-0.5)$).[5] Our results above from a model which incorporate rigidities in supply are consistent with this: the volume of electricity and water consumed falls to one-third of the current volume (=32/100). This reminds us that the size of the fall in demand is not a function of the supply side of the model, but rather a function of the demand side and in particular the elasticity of the demand curve. The supply side matters to calculate the fiscal cost. We return to discuss the sensitivity of our results to the elasticity of the demand curve in the conclusion.

Judged in terms of value, it might seem that there is a relative excess of infrastructure in the low-price subsidy regime. But the relative effects of the price reform on the value of inputs are not the same as on the volume of inputs. Figure 14 below describes the volumes of output and input, as indices, with the level of output in the heavily subsidized state being 100. Figure 14 shows that, while the heavily subsidized regime does indeed necessitate a much greater demand for infrastructure volume than the market regime (two and a half times more), the demand for fuel is distorted to an even greater extent, with four times more fuel needed.

Figure 14: Real Volumes of Inputs Used in Electricity and Water Production

	Scenario 1: Fixed at 10% of market price average	Scenario 2: Fixed at 55% of market price average (with compensating subsidy)	Scenario 3: Fixed at 70% of market price average (with compensating subsidy)	Scenario 4: Market Price (with compensating subsidy)
Electricity and water generated	100.00	42.64	37.80	31.97
Infrastructure input	49.70	21.65	19.25	20.73
Fuel input	45.30	17.17	14.97	10.26

Notes: All volumes indexed to the average volume of electricity and water generated in the heavily subsidized price scenario is 100 and the average volumes of inputs are equal to their value shares in that scenario.

---

[5] Note we should not use the first-order approximation formula of a percentage change to calculate the fall in demand (-0.5*9),because the price change is large.
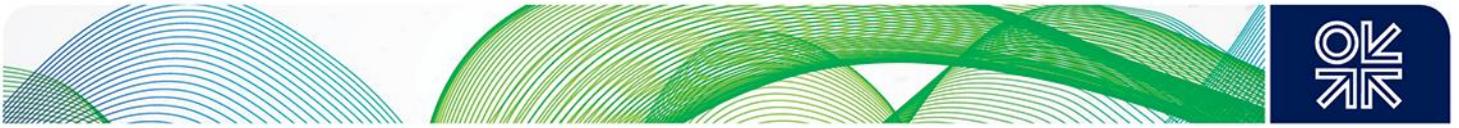
In Section 2.1, we emphasized that a crucial feature of electricity and water supply is the presence of a maximum capacity level that depends on existing infrastructure. Figure 15 describes how in the low-price subsidy regime, both the average level of output and the maximum level of output are higher than in other regimes and, in particular, are higher than in the market-price regime. However, output is proportionately closer to its maximum (and hence closer to the congestion zone) in the low-price regime than it is in the market-price regime. The difference is significant: the ratio between the two, called the capacity factor, is nearly 60 per cent in the low-price subsidy scenario, and hardly falls even when prices are fixed at 55 per cent and 70 per cent of the market price level in scenarios 2 and 3. Capacity is only created by allowing consumer prices to fluctuate at the market price level, when the capacity factor reaches 46 per cent. As we argued in Section 2.1, the capacity factor is a crucial determinant of how the system is able to cope with unforeseen shocks to demand. The US Electric Power Annual (EIA, 2011, Table 5.2) reports that in the late 1990s, when oil was more important for electricity generation in the USA, oil-fuelled power stations operated at a 20 per cent capacity factor, while its combined cycle gas-fuelled stations operated at 38 per cent. As 70 per cent of Kuwait's power comes from oil and 30 per cent from gas (MEED Insight, 2014), this implies that a target capacity factor would be about 25 per cent. Market pricing is shown to be a more efficient route to achieving these spare capacity levels. The current low fixed-pricing scenario suffers from congestion and even a higher fixed price – one that was two-thirds of the way between the current price and the market price – would strain capacity.

In summary, the results demonstrate that the potential fiscal benefits of reform are so large that consumers can be compensated on average whilst still leaving large fiscal savings and enabling a more reliable level of spare capacity. Estimates based on a model with realistic supply constraints and allowing for uncertainty and dynamics can differ from, and improve on, simple static calculations.
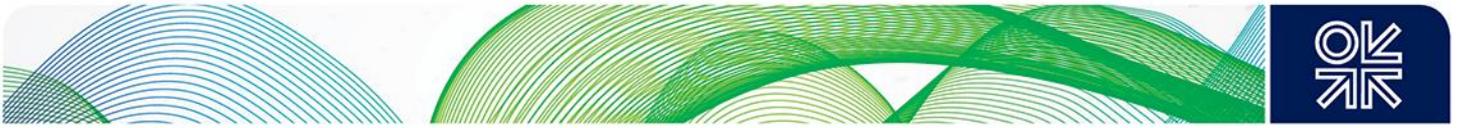
Figure 15: Capacity Factors and Congestion

	Scenario 1: Fixed at 10% of market price average	Scenario 2: Fixed at 55% of market price average (with compensating subsidy)	Scenario 3: Fixed at 70% of market price average (with compensating subsidy)	Scenario 4: Market Price (with compensating subsidy)
■ Maximum Capacity of Electricity and Fuel Generation (LHS scale)	168.06	73.20	65.09	70.09
■ Average Electricity and Water Generation Output (LHS scale)	100.00	42.64	37.80	31.97
Capacity Factor % (RHS scale)	59.50	58.25	58.07	45.61

Note: All volumes indexed so that the average volume of electricity and water generated in the heavily subsidized price scenario is 100.

7   The Rationale and Design of a Cash Transfer Scheme

We have estimated that price reform in the absence of a cash transfer would lead to a real income loss for consumers. According to our calculations, the consumption share of electricity and water supply costs will triple but would still remain below 1 per cent of consumption. Moreover, current and future generations of Kuwaitis, who are ultimately the beneficiaries of any savings, should gain from the fiscal savings of the market reform. Thus there may be no need to redress consumers on average for their loss on pure economic grounds.[6]

It follows that the cash transfer scheme should be judged on its ability to gain political acceptance for the reform and not as a necessary economic part of the price reform. But as the cash transfer should not discriminate according to usage, even if the cash transfers are substantial, the price reform is likely to have its opponents. This is because there will inevitably be some losers under the market scheme – heavy users of electricity and water – who cannot be compensated for their greater loss by cash transfers. Given the likely emergence of opposition to price reform, a public communication

---

[6] There is a separate argument for cash transfers as means of transferring natural resource wealth to its rightful owners. But here we are only concerned with cash transfers in the context of the elimination of subsidized prices.
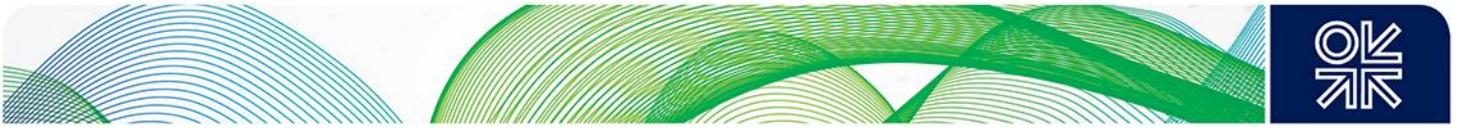
strategy would be a necessary part of this option. The losers are likely to be distinguished by their occupation or place of living, while winners are more likely to be dispersed among society. As the group of losers is easily superimposed over existing demarcations such as trade unions, societies, or constituencies, they can easily cohere into a lobby or a protest group. The natural emergence of an opposition explains why many subsidy price reforms are reversed (IMF, 2013). The key question facing Kuwaiti policymakers is, how can the cash transfer be designed to minimise the opposition to energy pricing reform?

One important reason why a cash transfer may be an ineffective acceptance strategy in Kuwait is that Kuwaitis already receive large cash transfers and payments from the state. For example, most Kuwaiti national workers are employed by the state, often in jobs which are not particularly onerous (El Katiri, Fattouh, and Segal, 2011). There is a danger that further transfers will be at best ineffective in promoting support for price reform and at worst deleterious for the economy if they lower the participation of Kuwaitis in the private sector labour market and fuel inflation. Given these considerations, it is worth contemplating some alternatives:

- One possibility is to make no change to current government transfers, but rather save all of the freed fiscal revenues for future generations. In this case, transparency and accountability in the treatment of savings should be paramount. Recent research (for example, Ross, 2013) has emphasized that citizens of oil-producing countries are very concerned with how natural resource wealth is saved or spent, as they recognize it for what it is: their birthright.

- A scheme to subsidize the human capital accumulation of Kuwaiti citizens could be another alternative to cash payments. The rationale for the human capital finance scheme is that it directly confronts what is felt to be the greatest economic challenge of oil-producing countries: the inability to translate resource wealth into privately earned human capital wealth. Thus transfers could be in the form of vouchers, grants, or cheap loans for study, childcare, female labour force participation, or rewards for health improvements, rather than cash.[7] Clearly the administrative costs of such a scheme would be quite substantial as courses would have to be provided and accredited; the performance of recipients continually monitored; and leakage and abuse minimized.

- A final possibility would be to use the savings to provide a temporary subsidy to encourage efficiency in electricity and water usage, in final consumers and also for intermediate users. Payments would have to be conditional on demonstrable *ex post* reductions in efficiency; otherwise such a scheme would run the risk of undoing the reforms. Hence the administrative costs would be substantial, as with the human capital scheme.

---

[7] It is important to note that some of these types of transfers are already available in Kuwait. Furthermore, a fundamental problem facing the education sector in Kuwait is not the quantity but the quality of education, so further inflows of funds may exacerbate some of the existing problems.
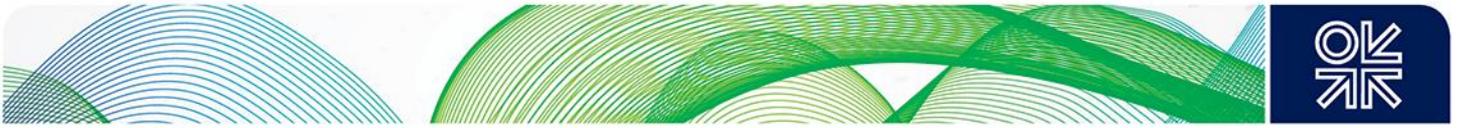
Targeting of a cash transfer scheme

In practice, a cash transfer scheme cannot be truly universal. Some individuals, such as the very young, those in prison, or citizens abroad are likely to be excluded from receiving any compensation. For Kuwait, beyond those straightforward exclusions, the most important dimensions over which a decision to target has to be made are i) final or intermediate consumers; ii) citizens or residents; iii) relative income differences; and iv) just adults or all citizens.

We should remind ourselves that the cash transfer scheme must not differentiate individuals according to any metric that is closely related to their consumption of electricity and water, otherwise the market-based pricing policy will be undone. The combined reform (market-based pricing and cash transfer) must give consumers the incentive to shift their consumption from power- and water-intensive activities.

In the Kuwaiti case, it seems clear that the transfer scheme should target final consumers.[8] Many intermediate consumers will be able to make efficiency improvements or pass on their costs to consumers and hence preserve their rate of return. In respect of production that is rendered uneconomic by the reform, such losses might well be considered a necessary part of promoting more water and energy efficiency. In order to help those producers whose business model is viable in the long run in the new regime, support policies must be conditional on these businesses demonstrating a greater efficiency of water and electricity, without substituting other fuels or running permanent losses. As argued above, any business relief must be conditional on planned reductions in energy and water usage and must be capable of being withdrawn if no such improvements are made.

As far as immigrants in Kuwait are concerned, they should also be thought of as intermediate providers of services to citizen-consumers. In 2011, Kuwait's population was around 3 million, 35 per cent of whom were Kuwaitis. If immigrants have market power, then they can pass on the extra costs to Kuwait citizen-final consumers according to the normal market mechanisms of higher wages and final output prices. If their profits are affected purely by the reform – so as to threaten their business – then it is optimal from an economic efficiency point of view not to subsidize their production, which must be power- or water-intensive.

Income distributional differentiation is a crucial issue in the design of cash transfers for many countries (Vagliasindi (2013) and Verme, El-Massnaoui, and Araar (2014)). However, there seems to

---

[8] In this respect, it is important to note that many tenants in multi-story commercial buildings and apartment buildings pay a rent that is inclusive of electricity and water. If higher costs of electricity and water prices are not passed to these tenants (or could not be passed due to contractual obligations), then the impact of a higher price on tenants' demand behavior is likely to be small, limiting the effectiveness of the price reform. This also raises the issue of who should benefit from the cash transfer, as owners (who are likely to be at the top of the income distribution) will be directly impacted as a result of higher electricity and water prices.
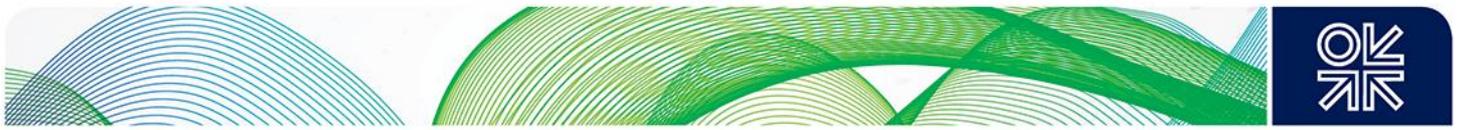
be, effectively, no absolute poverty among Kuwaiti citizens. There are, of course, relative income differences in Kuwait, but the benefits in terms of equity to be gained from differentiating the cash transfer by income would have to be weighed against the substantial administrative cost of means testing Kuwaitis. On these grounds, we would argue for a transfer undifferentiated by income.

The final aspect of differentiation to be considered is whether or not the young should receive the lump sum. The question of whether the young use many of these services is moot, but in any case the cash transfer should not discriminate of the amount of usage. Thus it seems fair to include them. After all, to leave out the young would lower the relative payment for large family households. In practical terms, the payment could either be given to the joint heads of households, or be made to a bank account to which the young person has access once they attain adulthood.

8   Conclusions and caveats

We have shown that there is a substantial benefit to be gained by allowing prices of electricity and water to rise to market levels. The fiscal savings are more than sufficient to compensate consumers on average for the loss, while still leaving a substantial surplus. We have demonstrated this important result in a model and method that takes account of the particular constraints of electricity and water co-generation and where both consumption and production inefficiencies exist. Yet we have also shown that the benefits from removing subsidies cannot be cleanly split into those from removing inefficiencies in consumption and those from removing inefficiencies in production. The spirit of this paper is that the two frictions are complementary, combining with each other in a way that defies such simplistic decompositions. For this reason, spending more on expanding scale while keeping prices artificially low is shown to be a costly route to alleviating shortages.

We confirmed that the low pricing regime is, to an important extent, responsible for the current situation – insufficient spare capacity in the provision of these services – in Kuwait. A move towards market pricing will complement investment in infrastructure and remove the distortions in the power sector. While electricity and water price charges will be much higher, the share of electricity and water in consumer budgets will not rise to the same extent and can be compensated by both the cash transfer and the utility benefits of a more efficient service.

The results show that a price level set (halfway or three quarters of the way) between the current low-price regime and the market-price regime can have large net fiscal benefits. Consumers may need time to adjust their consumption, for example to shift away from water- and electricity-intensive durable goods. Thus there may seem to be substantial benefits from a transitional regime, where prices gradually rise to market levels according to a predetermined path and thereafter following a moving average of market prices.
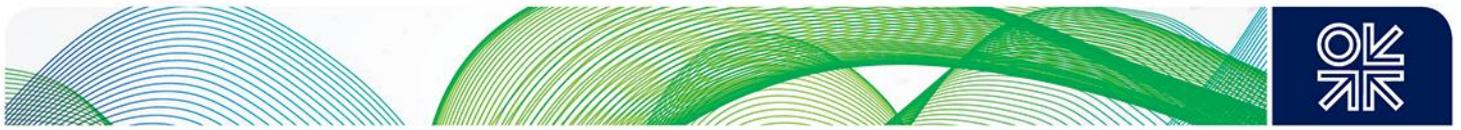
As appealing as this transition might seem, in terms of political economy, there are good reasons to argue for an abrupt jump to the market-price regime. While a long drawn out transition is less costly to reverse initially than a large discrete step, it is less likely to be carried through because consumers will not have the clear signal to make demand adjustments. Also, we have shown that the system is less strained if consumer prices are not fixed at any level but are allowed to adjust.

Another aspect of the transition decision is to whether to continue the lump sum transfers once the change to the market-price regime has been made. Our calculations have revealed that there is a net flow benefit to the reform relative to the current state, and so perhaps a continual payment could be justified. However, we argue that there is no economic necessity for a cash transfer, and also that the Kuwaiti government already makes large transfers to its citizens. Hence it would make sense to taper off the scheme once the benefits of the reform are widely acknowledged.

We have estimated that the level of demand under a current regime is three times what it would be under a market regime. This might seem implausibly large. In this regard, there are a few points worth noting. First, given that water and electricity prices in Kuwait are at most one tenth of the market price level, with an estimate of the long-run elasticity of demand of -0.5, a rise in market prices to ten to eleven times the current level would lower demand by one third of its current level, independent of the supply curve of our model. One could always argue that the elasticity of demand is smaller in than 0.5. For example it could be argued that in electricity and water, there is a base or subsistence level of demand which is completely inelastic and above that all other demand is elastic. If this level of subsistence were for example 40 per cent of total demand, then our calculations can be interpreted as saying that the new lower level of total demand (inelastic and elastic) would be 60 per cent of the current level (=0.6*(1/3)+0.4*1=0.2+0.4=60%). However, before accepting this argument, one would have to empirically demonstrate that the size of subsistence demand is as large as 40 per cent of total demand, or that demand is more inelastic than we assume for some other reason. It is not enough to say that demand is inelastic in Kuwait just because prices have not been raised since the 1960s.

Kuwait's electricity consumption is indeed far above that of other countries with the same level of Gross National Income (GNI) per capita but with prices closer to market levels. When we compare Kuwait to high-income non OECD countries we find that Kuwait's consumption of electricity per capita is 2.3 times the average of its peers. Considering that GNI per head (including oil revenues) is an overestimate of the true permanent income of the citizens of an oil producing state and that electricity and water prices in these other countries are also still somewhat below market levels, the excess consumption of electricity in Kuwait could well be three times what it would be at market price levels. The distortion in the consumption of water could be even worse.

There are three important caveats to our analysis, neither of which detracts from the quantitative importance of our findings.
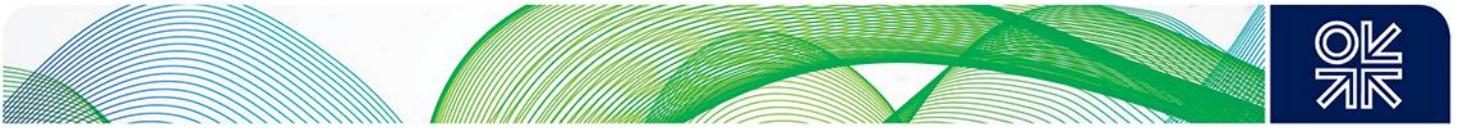
First, our model and method, though it is an innovation on the extant literature, does not take into account demand uncertainty. Allowing for demand uncertainty would add substantial computational cost to the solution method. We can expect that demand uncertainty due, for example, to unexpected fluctuations in temperature, would put more strain on systems that are run with insufficient capacity. On these grounds, we can reasonably argue that if we were to incorporate demand uncertainty, the relative costs of the low-price regime would be even greater than our estimates.

Second the model does not deal with electricity and water co-generation at the level of individual plants and instead is a high-level approximation of the production problem. A more detailed study could model the marginal cost curves of each generation plant in Kuwait taking into account the fuel mix, plant management and operating practices, co-generation, technical efficiency of the plant, and transmission and distribution losses, and simulate the response of total supply to shocks under different pricing structures. Similarly we have not dealt with the difficulties in hiring or firing marginal labour. In the model, labour is supplied elastically, and, even though labour is not a large share of costs, labour shortages can contribute disproportionately to electricity supply in countries like Kuwait with a small national workforce and strict hiring and firing laws. The incorporation of these production rigidities is left for future research.

A third caveat relates to the fact that we have not adjusted for the response of intermediate consumers, who will pass on the rise in their costs to Kuwait citizen-final consumers. This is particularly true if intermediate consumers and immigrants are not compensated with cash transfers (as we propose above), for then they will need to protect their profits. Our model does not consider separating out intermediate consumers of electricity and water. Consequently, losses in consumer welfare for final consumers are likely to go beyond those from the first-round effects.

In principle, one could calculate the first- and second-round effects of the price reform, but only at the cost of much greater complexity. One would need a model of intermediate trade, similar to Coady and Harris's Computable General Equilibrium Model (Coady and Harris, 2004) study of Mexico's food subsidies. Judging from calculations of carbon tax rises on electricity – such as Beznoska, Cludius, and Steiner (2012) – the sum of second-round losses across all consumption items could be half the size of the first-round effect on final consumer water and electricity. The key question is, then: if the entire cash transfer were given to final consumers, would this be enough to compensate them on average for a loss equal to one and a half times the first-round loss we have calculated? The residential sector represented 46.9 per cent of total power demand in 2009 and 70 per cent of desalinated water demand, while Kuwaiti resident citizens were about half of total residents. They would therefore be receiving a cash transfer equal to three or four times their consumer welfare loss from the first-round effect of the price rise. Hence a cash subsidy scheme directed at final citizen-consumers should amply compensate them on average for first- and second-round effects.
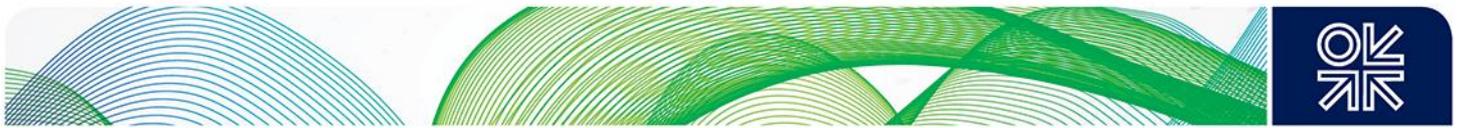
References

Al-Qudsi, S.S. and Al-Shatti, A.M. (1987a). 'Is The Lifeline A Viable Alternative To Kuwait's Fixed Electricity Tariff?', In Rowse, J.C. (ed.), 'World Energy Markets: Coping With Instability', Proceedings Of The Ninth International Conference, Calgary July 6–8, International Association Of Energy Economists.

Al-Qudsi, S.S. and Al-Shatti, A.M. (1987b). 'Restructuring Existing Electricity Tariff: A Welfare Assessment', In Rowse, J.C. (ed.), 'World Energy Markets: Coping With Instability', Proceedings Of The Ninth International Conference, Calgary July 6–8, International Association Of Energy Economists.

Agthe, D.E. and Billings, R.B. (2003). 'Price Rationing', Chapter 3 in Agthe, D.E., Billings, R.B. and Buras, N. (eds.) *Managing Urban Water Supply*, Water Science and Technology, Kluwer Academic Publishers, pages 23–43.

Alotaibi, S (2011). 'Energy Consumption In Kuwait: Prospects and Future Approaches', *Energy Policy*, Vol 39 (2) pages 637–42.

Alsumait, A.S., Sykulski, J.K., and Alothman, A.K. (2007). 'Application of Pattern Search Method to Power System Economic Load Dispatch Proceedings of the Third Iasted Asian Conference, Power and Energy Systems', April 2–4, 2007, Phuket Thailand.

Beznoska, M., Cludius, J., and Steiner, V. (2012). 'The Incidence of The European Union Emissions Trading System and the Role of Revenue Recycling: Empirical Evidence From Combined Industry- and Household-Level Data', Deutsches Institut Für Wirtschaftsforschung Discussion Paper, No 1227.

Bhattacharyya, S.B. and Blake, A. (2009). 'Domestic Demand For Petroleum Products in Mena Countries', *Energy Policy*, Vol 37 (4), pages 1552–60.

Canning, D. and Bennathan, E. (2000). 'The Social Rate of Return on Infrastructure Investment', World Bank Policy Research Working Paper.

Christensen, L.H. and Greene, W.E. (1976). 'Economies Of Scale In U.S. Electric Power Generation', *The Journal Of Political Economy*, Vol 84, Part 4, No 1, pages 655–76.

Coady, D.P. and Harris, R. L. (2004). 'Evaluating Targeted Cash Transfer Programs: a General Equilibrium Framework with an Application to Mexico, Evaluating Targeted Cash Transfer Program', Research Report No 137, International Food Policy Research Institute, Washington.
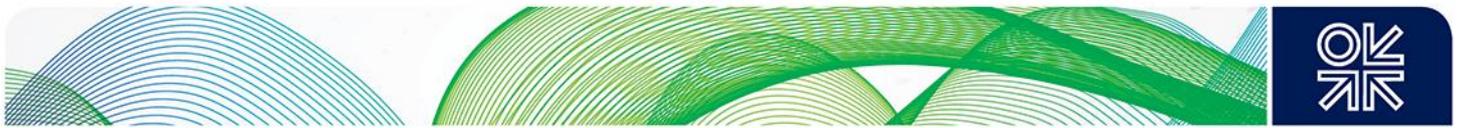
Cramton, P. and Ockenfels, A. (2012). 'Economics and Design of Capacity Markets for the Power Sector', *Zeitschrift Für Energiewirtschaft*, Vol 36, No 2, pages 113–34.

Darwish, M.A (2001). 'On Electric Power and Desalted Water Production in Kuwait', Desalination, Volume 138, Issues 1–3, pages 183–90.

De Boncourt, M. (2012). 'Powering Kuwait Into The 21st Century: Adopting A Sustainable Strategy', *Note De L'ifri*.

Deloittes (2013). 'Made In America: The Economic Impact of LNG Exports from the United States', a Report by the Deloitte Center for Energy Solutions and Deloitte Marketpoint Llc, Deloitte University Press.

EIA (2011). *Electric Power Annual 2009*, U.S. Energy Information Administration.

EIA (2013). *Kuwait Country Notes*, United States Energy Information Administration.

El-Katiri, L., Fattouh, B., and Segal, P. (2011). 'Anatomy of an Oil-Based Welfare State: Rent Distribution in Kuwait', in David Held and Kristian Ulrichsen (eds.), *The Transformation of the Gulf States: Politics, Economics and the Global Order*, Routledge.

Espey, J.A. and Espey, M. (2004). 'Turning on the Lights: a Meta-Analysis of Residential Electricity Demand Elasticities', *Journal Of Agricultural and Applied Economics*, Vol 36 (1), pages 65–81.

Espey, M., Espey, J., and Shaw, W.D. (1997). 'Price Elasticity of Residential Demand for Water: a Meta-Analysis', *Water Resources Research*, Vol 33 (6), pages 1369–74.

Fattouh, B. and El Katiri, L. (2012). 'Energy and Arab Economic Development', Arab Human Development Report Research Paper Series, United Nations Development Programme.

KISR (2011). 'Water Program to Develop New Paradigm for Water Management in Kuwait', *KISR Connect*, Issue 47, Winter.

Gramlich, E.M. (1994). 'Infrastructure Investment: a Review Essay', *Journal of Economic Literature*, Vol 32 (3), September 1994, pages 1176–96.
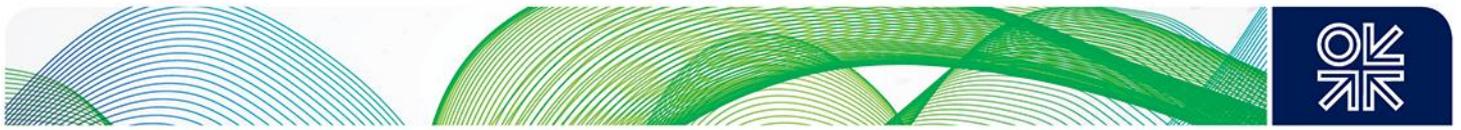
Groth, C and Khan, H. (2010). 'Investment Adjustment Costs: An Empirical Assessment', *Journal of Money, Credit and Banking*, Vol. 42(8), pages 1469–94.

Hamoda, M.F. (2001). 'Desalination and Water Resource Management in Kuwait', *Desalination*, Volume 138, Issues 1–3, 20 September 2001, pages 385–93.

Hogan, W.W. (1992). 'Contract Networks for Electric Power Transmission', *Journal of Regulatory Economics*, Vol 4 (3), pages 211–42.

IMF (2011). *Kuwait: Statistical Appendix*, IMF Country Report No 11/219 International Monetary Fund, July 2011.

IMF (2012). *Kuwait: Selected Issues and Statistical Appendix*, IMF Country Report No 12/151 International Monetary Fund, July 2012.

IMF (2013). *Energy Subsidy Reform: Lessons and Implications*, International Monetary Fund, 2013.

Kuwait Central Statistical Bureau (2011). *Annual Statistical Abstract*, Chapter 9, Electricity and Water.

Kuwait Central Statistical Bureau (2011). *Annual Statistical Abstract*, Chapter 14, Household Income and Expenditure and Index Numbers.

Kuwait Central Statistical Bureau (2014). *Consumer Price Index Numbers*, January 2014.

MEED Insight (2014). *Mena Solar Power Market and Projects Report 2014*, A MEED Insight Report.

Milutinovic, M., Murtaugh, K.A., and Eltahir, E.A.B. (2006). *A Proposal for Water Pricing In Kuwait*, MIT, 2006.

Missimer, T.M., Sinha, S., and Ghaffour, N. (2012). 'Strategic Aquifer Storage and Recovery Of Desalinated Water to achieve Water Security in the GCC/Mena Region', *International Journal Of Environment and Sustainability*, Vol 1(3), pages 87–99.

McCawley, P (2010). 'Infrastructure in Asian Developing Countries', *Asian Pacific Economic Literature*, Vol 24 (1).
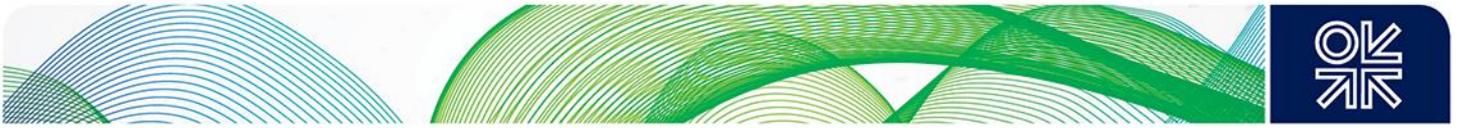
Ross, M.L. (2013). *The Oil Curse: How Petroleum Wealth Shapes the Development of Nations*, Princeton University Press, 2013.

Stoft, S. (2002). *Power System Economics: Designing Markets for Electricity*, IEEE Press, United States.

Turvey, R., (2000). 'Infrastructure Access Pricing and Lumpy Investments', *Utilities Policy*, Elsevier, Vol. 9(4), pages 207–18.

United States Bureau of Economic Analysis (2004). *Depreciation Rates*.

Vagliasindi, M. (2013). 'Implementing Energy Subsidy Reforms: Evidence from Developing Countries' (Directions in Development), International Bank Of Reconstruction and Development and The World Bank, Washington D.C., United States.

Verme, P. El-Massnaoui, K., and Araar, A. (2014). Reforming Subsidies In Morocco, *Economic Premise*, The World Bank, Number 134.

Vickrey, W. S.(1963). 'Pricing In Urban and Suburban Transport', *The American Economic Review*, Papers and Proceedings, pages 452–65.

Appendix - Solving the model for the subsidized price mode

Substituting out for $p_{y,t}$ in the expression for the marginal revenue product for infrastructure from the marginal revenue product for fuel (equation (7)):

$$p_{x,t} = \widetilde{p_{k,t}} \frac{\varepsilon}{\alpha} \frac{k_t}{x_t} \frac{(1-\omega z_t)}{1-\varepsilon(1-\omega z_t)}. \tag{A2.1}$$

Substituting out for the volume of fuel from the definition of short-run output

$$k_t = (o_t)^{\frac{1}{\alpha}} (\bar{l})^{\frac{-(1-\alpha)}{\alpha}}$$

gives

$$p_{x,t} = \widetilde{p_{k,t}} \frac{\varepsilon}{\alpha} \frac{(o_t)^{\frac{1}{\alpha}}(\bar{l})^{\frac{-(1-\alpha)}{\alpha}}}{x_t} \frac{(1-\omega z_t)}{1-\varepsilon(1-\omega z_t)}. \tag{A2.2}$$

Setting demand for electricity and water from equation (11) equal to the supply in equation (1) and using equation (8) to eliminate z_t yields:

$$\bar{d}\left(\frac{1-\varsigma}{\varsigma}\widetilde{p_{c,t}}\right)^{-\frac{1}{\xi}} = o_t \left(\frac{x_t}{o_t+\omega x_t}\right)^{\varepsilon} \tag{A2.3}$$

Substituting out for z_t from equation (8) into equation (A2.2) and rearranging:

$$p_{x,t} = \widetilde{p_{k,t}} \frac{\varepsilon\omega}{\alpha} \frac{(o_t)^{\frac{1}{\alpha}}(\bar{l})^{\frac{-(1-\alpha)}{\alpha}}}{(1-\varepsilon)o_t+\omega x_t}. \tag{A2.4}$$

Consider the first-order conditions to the problem expressed in equation (9) for choosing the utility-maximizing amount of infrastructure investment and stock:

$$\lambda_t = (\pi_t)^{-\gamma}\beta^t(1+\eta)^{-\gamma t}$$

$$0 = \lambda_t\left(p_{x,t} - c_0 - 1 - \phi\left(\frac{x_t}{x_{t-1}} - 1\right)\right)$$

$$+ E_t\left[\lambda_{t+1}\left((11\delta_x) - \frac{\phi}{2}\left(\frac{x_{t+1}}{x_t} - 1\right)^2 + \phi\left(\frac{x_{t+1}}{x_t} - 1\right)\frac{x_{t+1}}{x_t}\right)\right] \tag{A2.5}$$

Combining the two first-order conditions:

$$0 = \left(p_{x,t} - c_0 - 1 - \phi\left(\frac{x_t}{x_{t-1}} - 1\right)\right)$$

$$+ E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left((1-\delta_x) - \frac{\phi}{2}\left(\frac{x_{t+1}}{x_t} - 1\right)^2 + \phi\left(\frac{x_{t+1}}{x_t} - 1\right)\frac{x_{t+1}}{x_t}\right)\right]$$

Or
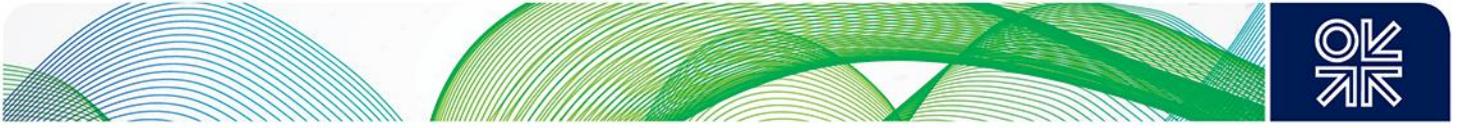
$$0 = \left(p_{x,t} - c_0 - 1 - \phi\left(\frac{x_t}{x_{t-1}} - 1\right) \right) + \beta \; (1 +$$

$$\eta)^{-\gamma} E_t \left[\frac{\left(p_{x,t+1}x_{t+1} - c_0 x_{t+1} - i_{t+1} - \frac{\emptyset}{2}\left(\frac{i_{t+1}}{x_t} - \delta_x\right)^2 x_t \right)}{\left(p_{x,t}x_t - c_0 x_t - i_t - \frac{\emptyset}{2}\left(\frac{i_t}{x_{t-1}} - \delta_x\right)^2 x_{t-1} \right)} \left((1 - \delta_x) - \frac{\phi}{2}\left(\frac{x_{t+1}}{x_t} - 1\right)^2 + \phi\left(\frac{x_{t+1}}{x_t} - 1\right)\frac{x_{t+1}}{x_t} \right) \right]$$

$$(A2.6)$$

As complicated as this might seem, equation (A2.6) simplifies in the deterministic steady state, as all prices are then fixed for the infrastructure provider, due to government policy; there is no uncertainty and no dynamics. Hence, equation (A2.6) implies that in the deterministic steady state, infrastructure prices are fixed at the social rate of return net of maintenance costs:

$$0 = (p_x - c_0 - 1) + \beta \; (1 + \eta)^{-\gamma}(1 - \delta_x)$$
$$\Rightarrow p_x = 1 - \beta \; (1 + \eta)^{-\gamma}(1 - \delta_x) + c_0$$

Equations (A2.3) and (A2.4) can now be solved numerically to yield the deterministic steady state of x_t, o_t, and all other variables.

Equations (A2.1) to (A2.6) hold in the dynamic state. However, in this case we cannot simplify equation (A2.6), and prices are no longer fixed.

Substituting out for $p_{x,t}$ from equation (7) and for z_t from equation (8) in expression (A2.2) gives:

$$\tilde{p}_{k,t} \frac{\varepsilon\omega}{\alpha} \frac{(o_t)^{\frac{1}{\alpha}}(\bar{l})^{\frac{-(1-\alpha)}{\alpha}}}{(1-\varepsilon)o_t+\omega x_t} = p_{y,t}\varepsilon\frac{o_t}{x_t}\left(\frac{x_t}{o_t+\omega x_t}\right)^\varepsilon \left(1 - \omega\frac{x_t}{o_t+\omega x_t}\right). \qquad (A2.7)$$

Our numerical solution method is as follows. We first create a grid of 100 values each for the state variables, $p_{k,t}$ and x_t. The grids are centred on the known deterministic means of the two variables and are not evenly spaced, but have finer grading closer to the mean. But they also include some extremely high and low values. However, all values of both variables in the grid are positive.

Then for each pair of values of $p_{k,t}$ and x_t in the grid, we solve (A2.7) for o_t and thus all other variables. This gives us a grid of all variables in the market price mode of the model, conditional on values for $p_{k,t}$ and x_t.

Then we simulate 10,000 series of market fuel prices, using equation (6) and beginning at e^μ for a horizon of 30 years.

We assume that an infrastructure provider decides how much to invest according to the following rule:
$$x_t = \bar{x} + G_x(x_t - \bar{x}) + G_k(k_t - e^\mu) \qquad (A2.8)$$
where the parameters $\bar{x}$, G_x and G_k are to be determined as the values that maximize the expected sum of discounted utilities of infrastructure providers. Then for each Monte Carlo path for fuel prices, we can generate a path of values for x_t, conditional on a set of values for $\bar{x}$, G_x, and G_k. We match these values to the closest values on their grids and, using these coordinates, we can calculate the time paths for all the variables in the model for each of the 10,000 Monte Carlo simulations. This enables us to calculate the Monte Carlo equivalent of the right-hand side of the first-order condition (A2.6):

$$f(\bar{x}, G_x, G_k) = \sum_{t=q}^{10,000} \left(p_{x,t} - c_0 - 1 - \phi \left(\frac{x_t}{x_{t-1}} - 1 \right) \right) + \beta \ (1 +$$

$$\eta)^{-\gamma} \sum_{t=q}^{30} \sum_{m=1}^{10,000} \left[\frac{\left(p_{x,t+1} x_{t+1} - c_0 x_{t+1} - i_{t+1} - \frac{\emptyset}{2} \left(\frac{i_{t+1}}{x_t} - \delta_x \right)^2 x_t \right)}{\left(p_{x,t} x_t - c_0 x_t - i_t - \frac{\emptyset}{2} \left(\frac{i_t}{x_{t-1}} - \delta_x \right)^2 x_{t-1} \right)} \left((1 - \delta_x) - \frac{\phi}{2} \left(\frac{x_{t+1}}{x_t} - 1 \right)^2 + \right.$$

$$\left. \phi \left(\frac{x_{t+1}}{x_t} - 1 \right) \frac{x_{t+1}}{x_t} \right) \right] \qquad\qquad\qquad\qquad (A2.9)$$

where data from the first 3 years are ignored.

A pattern search algorithm is put to work to find the values of $\bar{x}, G_x, G_k$ that puts the value of $f(\bar{x}, G_x, G_k)$ closest to zero.

Inserting the optimal values for these parameters $\left(\hat{x}, \hat{G}_x, \widehat{G}_k \right)$ into equation (A2.9) gives us the optimal decision rule of the infrastructure provider, solving the model. After applying another Monte Carlo simulation, or even reusing the previously simulated Monte Carlo paths for market fuel prices, we can calculate consumer welfare and fiscal costs according to equations (13) to (16), replacing the expectational operator with the summation across Monte Carlo paths where necessary:

$$E_t[r_{t+s}] \approx \sum_{m=1}^{10,000} r_{t+s} \qquad\qquad\qquad\qquad (A2.10)$$