The Market for Electricity Generators in Lebanon: Demand Functions and Pricing Strategy

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Abstract
The purpose of the present case is to build up and study a theoretical approach to the market of electricity generators in Lebanon. This private market, which is largely unregulated, has lately co-existed with the formal and state-owned natural monopoly of electricity, Électricité du Liban. The reasoning is based on postulating demand functions for electricity, and carrying out a maximization of net profits. In some other instances maximization of revenue is the criterion. The demand functions are specified both linearly and multiplicatively. The variables of interest are the equilibrium price, the revenue per subscriber, the profit per subscriber, the cost per subscriber, the service level, and the Internal Rate of Return (IRR). The paper considers both partial and round-the-clock private provision of electricity. The latter is much less profitable and will not be selected, even if it is technically feasible. To be realistic the modeling assumes a two-tier pricing policy. In addition second-order price discrimination is contemplated, and its monetary advantage is measured.

Key words: *electricity generators, demand for electricity, linear and multiplicative functions, profit maximization, revenue maximization, equilibrium price, subscriber characteristics, service level, profitability (IRR), price discrimination*

1. Introduction

Private electricity generators are abundant in Lebanon. They are a stable and a potentially growth industry as long as they remain needed. Unfortunately this need is not expected to wane in the foreseeable future. And surprisingly, these generators are regarded as a necessary and unavoidable substitute to the public sector, and they provide a decent service for a good that is inherently a public good. However, little is known about how pricing policy is established in the market place. This note will provide a brief reading of the partial analytics and comparative statics. Five main findings are enumerated. One, evidence is provided that a 100% round the clock service level is not optimal even if it is theoretically feasible. The loss of profit by adopting such universality is estimated and is substantial. Second, the demand functions for electricity can be stated in two equivalent forms, multiplicatively and additively, and both forms are reasonable. Three, a two-tier pricing strategy is definitely more profitable than a one-tier strategy. This agrees with the prediction of a second order price discrimination policy. Four, the optimal tariff is for charging two fees, a variable one, which depends on usage, and a fixed one that extracts the totality of the consumer surplus. Five, when total revenues instead of net profits are maximized, the puzzling and unrealistic conclusion is that the optimal service level should be 100%. Therefore, in this case, which is based on the assumption of costs being fixed, the analysis is not tenable, and does not conform to reality, and hence the underlying assumption of fixity of costs does not stand. All along, the optimal price for electricity usage for each given scheme is solved for, and specific price estimates provided, catalogued, and presented. Moreover, and wherever possible, values for monthly total net profits per subscriber are derived from the analysis.

2. The base scenario

The marginal cost (c) is to be assessed. Assume a constant marginal cost (c). This is not totally unrealistic because the output of one generator is a direct function of diesel oil usage. A multiplication of the diesel oil usage by two will in all likelihood increase generator output by a factor of 2. The marginal cost was estimated to be US 17 cents (World Bank, 2020). Around that time, i.e. in May 2020 or slightly before, the price per gallon of diesel oil was US-$ 2.5. Since the current diesel price is around US-$ 5.6 (US EIA, 2022), then the current marginal cost is estimated to be US-$ 0.38 per kW (=0.17*5.6/2.5). The model implies a total yearly cost (TC) to the owner of the generator $TC = c * Q = 0.38 * Q$, where Q is the yearly energy consumption per household. Net yearly dollar profits (π) per household or per subscriber are

$$\pi = TR - TC = (p - c) * Q = (p - 0.38) * Q.$$

Owners of generators seek to maximize the profit π by changing the price level p or the tariff rate. For this purpose a demand function needs to be estimated. Assume a price elasticity of demand of -3.35. The demand function is posited to be isoelastic and is calibrated to solve for the actual supply with a service level of around 50%, assuming that what is actual is also what is optimal:

$$Q = A * p^{-3.35} \Rightarrow p = \left(\frac{Q}{A}\right)^{-\frac{1}{3.35}}$$

The parameter A is supposed to be 880. Hence

$$p = \left(\frac{Q}{880}\right)^{-\frac{1}{3.35}} = 6.94 * Q^{-\frac{1}{3.35}}$$

Inserting this value in the profit function gives

$$\pi = \left(6.94 * Q^{-\frac{1}{3.35}} - 0.38\right) * Q = (6.94 * Q^{1-\frac{1}{3.35}}) - 0.38Q$$

Maximum π is obtained when

$$6.94 * \left(1 - \frac{1}{3.35}\right) * Q^{-\frac{1}{3.35}} - 0.38 = 0 \Rightarrow Q = 5{,}134$$

Which implies a monthly usage of 428 kW or an electricity supply of 12.4 hours a day, a service level of 52% which is approximately equal to the actual supply statistic. This assumes that an hour of electricity requires 1.15 kW per hour (Salame, 2021). At such an actual electricity consumption the implied average equilibrium price per kW is US-$ 0.59, the monthly revenue per subscriber is around US-$ 252 on average, and the average monthly profit per subscriber is US-$ 90. These figures are somehow bigger than anticipated. However, they do not include any fixed cost, or relevant service charge, or any allocated overhead.

Assuming one million subscribers, and a constant discount rate of 10%, the breakeven capital cost of the generator is US-$ 10.8 billion = US-$ 90*12*1,000,000/0.10. This is consistent with a capital cost of US-$ 1,260 million for a 50 Mw generator ≈ US-$ 10,800 million*50,000,000/(428*1,000,000). See the pricing in https://en.tech-expo.ru/des-50MWt/**.** From this crude analysis it becomes apparent that the return is 10% on average for a generator owner. This crude analysis assumes an infinite horizon. If the horizon is reduced to 10 years, with no monetary loss on the salvage value, the average return or profitability has the same breakeven capital cost, and the same Internal Rate of Return IRR (Brealey *et al.*, 2018). However, if there is a 10% loss on the salvage value then the IRR is 9.35%. If there is a 20% loss the IRR is 8.66%. A 50% cut will reduce the IRR to 6.25%. A 100% cut will reduce the IRR to exactly 0%.

If it is feasible, supplying electricity round the clock would increase individual consumption to 10,074 kW a year, = 24*365*1.15, or to 840 kW per month. At such a level the unit price per kW is US-$ 0.483 and the monthly profit from a subscriber is US-$ 86.50, a fall of around 4%. The IRR would be 9.61% instead of 10%. The IRR falls from 6.25% to 5.78% for a 50% cut in the salvage value of the generator. This explains why even if it were feasible to provide electricity round the clock, it will not be profitable for the owners of generators to do so. With a 100% service level, the net fall in the total yearly profits of the industry is hefty at around US-$ 42 million
= (90-86.5)*12*1,000,0000. With these estimates the market for generators tops a yearly turnover, or total revenues, of US-$ 3 billion (250*12*1,000,000).

If electricity usage is for 10 amperes then the price elasticity of demand can be found by setting to zero the following expression and solving for α

6.94*(1-1/α)*(10,268)^(-1/α)-0.38=0

The solution is for an $\alpha = 3.5834$. The demand function becomes

$Q = 880 * p^{-3.5834}$=10,268 $\Rightarrow p = US - \$ \, 0.504$

The monthly revenue is US-$ 431.25, the monthly cost is US-$ 325.15, and the monthly profit is US-$ 106.10. If the capital cost of the generators is set at US-$ 10.8 billion, the IRR is 11.7%. With a 50% cut on the salvage value and a useful life of 10 years the IRR is 8.40%.

If it is feasible, supplying electricity round the clock would increase individual consumption to 20,148 kW a year or to 1,679 kW per month. At such a level the price is US-$ 0.4174 and the monthly profit from a subscriber of US-$ 62.80, a fall of around 41%. The IRR would be 6.97% instead of 11.7%. This explains why even if it is feasible to provide electricity round the clock, it will not be a profitable alternative to the owners of the generators. The net fall in the total yearly profits of the industry is hefty at around US-$ 519.6 million = (106.10-62.8)*12*1,000,0000. Overall, and with these estimates, the market for generators tops a turnover of US-$ 5.175 billion (431.25*12*1,000,000).

3. Linear demand functions

In order to check for robustness a linearization of the demand function is attempted. Assume that

$Q = \alpha - \beta P$ with the parameters $\alpha > 0$ and $\beta > 0$

where Q is demand (or usage) for say a 5 kilo watt package and P the tariff, or the price rate. For such a linear equation, two points are enough to determine α and β. The first point is Q =5134 and P =0.59, and the second point is Q =10,074 and P =0.483. The solution is

$Q = 32{,}373 - 46{,}168P$

At such values

$$total\ profit = PQ - cQ = (P - 0.38) * Q = \left[\frac{32373 - Q}{46168} - 0.38\right] * Q$$

The maximum profit is reached at $Q = 7{,}414.6$ which amounts to a monthly 617.88 kW, 537 electricity hours per month, 17.9 hours of service per day, or a service level of 75%. The price is US-$ 0.5406. Total profit is a monthly US-$ 99.23. This compares with a monthly of US-$ 90 obtained by an isoelastic demand function.

A round o'clock service will result in a price of US-$ 0.483 per kW, or a monthly profit of US-$ 86.47. Providing electricity round the clock will result in a yearly loss of US-$ 153 million = (99.23-86.47)*12*1,000,000 for the industry.

Is there a way to increase profits by charging an additional fixed fee? This is possible if this fixed fee is set equal to the consumer surplus, in order to extract the maximum from the subscriber. The consumer surplus equals

$$0.5 * (P_{max} - P^*)Q^* = 0.5 * (0.7012 - 0.5406) * \frac{7{,}414.6}{12} = \frac{595.4}{12} = US - \$\ 49.62$$

Where P_{max} is the price for a zero level of usage Q, and $P^*$and $Q^*$are the equilibrium price and quantity respectively. Hence the tariff for a 5-ampere subscription should be

$$0.5406Q + 49.62 = 0.5406 * \frac{7{,}414.6}{12} + 49.62 = US - \$\ 383.65$$

A similar analysis can be done for a 10-ampere subscription. In the linear equation of the demand function, the first point is Q =10,268 and P =0.504, and the second point is Q =20,148 and P =0.4174. The demand function is solved to be

$Q = 67{,}768.4 - 114{,}088P$

And total profit is

$$total\ profit = (P - c) * Q = (P - 0.38) * Q = \left[\frac{67678.4 - Q}{114088} - 0.38\right] * Q$$

Which is maximized for Q =12,162.5 which implies a price $P = US - \$\ 0.4866$, a total profit of US-$ 108.05, a service level of 14.7 hours a day, or a service level of 61%.

Is there a way to increase profits by charging a fixed fee? The consumer surplus must hence be extracted. This equals

$$0.5 * (P_{max} - P^*)Q^* = 0.5 * (0.5932 - 0.4866) * \frac{12{,}162.5}{12} = US - \$\ 54.02$$

Hence the tariff for a 10-ampere subscription, and a pricing policy to extract all the consumer surplus, should be

$$0.4866Q + 54.02 = 0.4866 * \frac{12{,}162.5}{12} + 54.02 = US - \$\ 547.21$$

4. Fixed costs

Another general category of pricing policy exists, on the assumption that production costs do not vary with usage, and are predictable, which means that there is a fixed production cost, which is equal to a technical production coefficient multiplied by the unit price of diesel oil, which is the major input factor. This is acceptable as an assumption because a maximum deterministic usage level is usually imposed by owners of generators, also because all costs are measured herein in a safe and stable currency, the US dollar, and finally because the dollar market price of diesel oil, while volatile in the short run, is much less volatile and is steadier in the long run. Hence production is fairly constant at this maximum, and the fixed cost drops out from the maximization of profits because it is fixed. Of course there may be two such fixed prices, like one for a 5 kilo watt subscription and the other for a 10 kilo watt. For both, maximization of profits is equivalent to maximization of total revenue. Here again, the only necessary input is the individual demand function of electricity use. This function takes the classic archetypal form $Q = \alpha - \beta P$.

Total revenue per customer is $QP = (\alpha - \beta P)P$. The program consists of maximizing total revenue, $(\alpha - \beta P)P$, with respect to P. This is equivalent for having the marginal revenue equal to zero, obtained by solving for the first-order condition for a maximum. The optimal tariff is then obtained to be

$$\frac{\partial[(\alpha - \beta P)P]}{\partial P} = 0 \Rightarrow P = \frac{\alpha}{2\beta}$$

At this tariff rate, demand per customer Q is $\alpha/2$, and the fixed fee per customer F equals

$$F = P * Q = \frac{\alpha}{2\beta} * \frac{\alpha}{2} = \frac{\alpha^2}{4\beta}$$

Therefore it is enough to know the demand function, with its two parameters, α and β, to find the fixed fee. Assume the first demand function is

$$Q = 32{,}373 - 46{,}168P$$

At such values

$$P = \frac{\alpha}{2\beta} = \frac{32{,}373}{2 * 46{,}168} = 0.3506 \ \Rightarrow Q = 16{,}186.50$$

This usage is not feasible because maximum Q is 365*24*1.15=10,074 kW. The service level is therefore bound to be 100%. At such a demand level the price is US-$ 0.4830. Hence the monthly revenue is US-$ 405.50, the monthly cost is US-$ 319.00 and there is a monthly profit of US-$ 86.50.

If the demand function for say the 10 Kilo Watt tier is different at

$$Q = \theta - \mu P = 67{,}768.4 - 114{,}088P$$

Then the price that maximizes total revenue is

$$P = \frac{\theta}{2\mu} = \frac{67{,}768.4}{2 * 114{,}088} = 0.2970 \Rightarrow \ Q = 33{,}884.2$$

Maximum Q is 365*24*1.15*2=10,074*2=20,148 kW. The service level is hence 100%. At such a demand level the price is US-$ 0.4174. The monthly revenue is US-$ 700.81, the monthly cost is US-$ 638.02 and there is a monthly profit of US-$ 62.79.

5. Second degree price discrimination

The option to have a 2-tier pricing strategy is selected from the usual argument that a 2-tier policy is more profitable than a one-tier strategy. In the literature the 2-tier policy is referred to as a second degree price discrimination which leverages profits (Nicholson and Snyder, 2012). What are the characteristics of a one-tier pricing strategy for, e.g. both 5 amperes and 10 amperes, and is such a strategy indeed less profitable? Start by considering total demand for the two price schedules when there is no discrimination:

$$Q = Q_1 + Q_2 = \ Q = 32{,}373 - 46{,}168P \ + 67{,}768.4 - 114{,}088P$$
$$= 100{,}141.4 - 160{,}256P$$

The optimum price for the fixed-fee one-tier pricing strategy occurs when

$$P = \frac{100{,}141.4}{2 * 160{,}256} = 0.3124$$

At such a price demand is higher than what is feasible at Q =50,077.43 kW. Maximum coverage is 1.15*24*365*3=30,222 kW. A 100% service level corresponds to a price of US-$ 0.4363. Total gross profit is US-$ 1,098.82, which is produced from 3 customer equivalent units, making a gross profit per unit of US-$ 366.27. This should be compared to a total gross profit per subscriber, when discrimination is implemented, equal to

$$\frac{\left(\frac{\alpha^2}{4\beta} + \frac{\theta^2}{4\mu}\right)}{3} = US - \$\frac{1{,}311.55}{3} = US - \$\ 437.18$$

As expected discrimination causes a sizeable pecuniary benefit. The extra profit is estimated to be US-$ 851 million a year, which is quite substantial, and equals US-$ (437.18-366.27)*12*1,000,000.

6. Conclusion

The foregoing analysis is also applicable to a natural monopoly of electricity provision, like Électricité du Liban. More so, it is applicable to a regional municipality energy exploitation, like the Zahlé electricity project. In all situations the individual demand function is the key argument, and it is commendable to replicate and duplicate the economic comportment in the informal market of electricity generators. The only difference is that a natural monopoly, or a regional municipality facility, will be required to equate the tariff to the average cost, a scheme which produces zero economic profits to the facility, and thereby achieves economic fairness and equity. However, since in the present note average and marginal costs are equal, because of the assumed production technology, the inferences remain the same. The modelling of the market so far has been restricted to a maximum two-tier pricing scheme. It can be easily generalized to a three-tier scheme or more.

As a general conclusion the key element in the analysis is the determination of the demand function. From there all other inferences naturally follow. Estimated monthly profits vary in a tight range mostly between US-$ 80 and US-$ 100. Investing resources in money and human capital to estimate the actual market demand function for electricity is ultimately crucial and should be highly rewarding. Such a more accurate demand function is not expected to deviate much from the stated demand functions in this note, but may lead to more precise policy decisions.

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