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The Inverted Block Rate: An Alternative to Flat Rate Billing

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Abstract

Energy suppliers typically charge their residential customers for the amount of electrical energy consumed per billing period. There are numerous billing schemes that can be used; one of the more common is the flat rate, in which all customers are subject to the same price regardless of the total energy consumed and the system demand at the time of consumption. Despite its simplicity, the flat rate is not cost reflective, often resulting in cross-subsidization, and does not allow the energy supplier to create price signals.

Although other, more progressive billing schemes, such as time-of-usage billing, exist, some energy suppliers and their customers are reluctant to adopt them because of the cost of replacing existing induction meters with electronic interval meters.

The inverted block rate is an alternative to the flat rate that does not require the replacement of the customer's induction meter. In the inverted block rate, the customer's consumption is divided into blocks; each block has a price per unit of energy consumed, which increases with each succeeding block. The customer's bill is simply the sum of consumption per block multiplied by the energy price associated with each block. By varying each block's price, the energy supplier can introduce price signals as well as addressing the issue of cross-subsidization.

This paper compares the inverted block rate with the flat rate, and presents a hypothetical implementation of the inverted block rate using residential metering data from a small Canadian electrical utility.

1 Introduction

Electricity is central to the development and well-being of all modern societies. Since electricity does not exist naturally in a form that can be readily used, it is necessary to generate electricity from other sources of energy, including coal, oil,

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natural gas, nuclear, hydroelectric, and other renewables. Once it has been generated, an energy supplier[2] sells the electricity to its customers. Revenue from the sale of electricity must allow the energy supplier to (Skrotzki, 1990):

- Recover the cost of capital investments (generating equipment, transmission and distribution equipment, and other operating equipment);
- Recover the cost of operation, supplies, and maintenance of the equipment;
- Recover the cost of metering equipment, billing and collection costs, and miscellaneous services;
- Allow a satisfactory rate of return on the capital investment.

Obtaining revenue from customers (that is, billing) requires the energy supplier to measure each customer's energy consumption, or demand, or both[3], over a given billing period using some form of metering equipment. The customer's bill is then determined from this information and the rate model associated with the customer's rate class.

At a minimum, a rate model is a means of generating revenue from customers. However, rate models can do far more than this; judiciously applied, they can influence customer consumption patterns by rewarding changes in behaviour. Until recently, many energy suppliers employed rate models that encourage consumption; for example, by decreasing the price per unit of energy as consumption increased (Patterson, 1999).

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[2] For the purposes of this paper, an 'energy supplier' is a company (such as a vertically-integrated utility) or group of companies (such as generators and network operators) that supply electricity to a customer.

[3] A customer consumes a certain amount of energy over a given period, usually expressed in kilowatts-per-hour or kilowatt-hours. During this period, the demand for energy can vary between a minimum and a maximum; the energy supplier must be able to meet the customer's maximum demand for energy. Demand can be expressed in kilowatts or megawatts.

Peak demand occurs when the sum of all customer demands are the greatest during a given period; for example, there are daily peaks and annual or system peaks. The energy supplier must have sufficient capacity to meet the highest peak demand during the year.

However, with increasing fuel prices and growing environmental concerns over methods of electrical generation, many energy suppliers, either through shareholder pressure or government legislation, are being forced reconsider their business strategies. These new strategies often focus on energy efficiency, either through adopting new, fuel-efficient technologies (for example, switching to new types of generation such as Combined Cycle Gas Turbines) or modifying customer habits (for example, implementing Demand Side Management (DSM) programs that encourage reductions in demand, or energy consumption, or both).

There are many approaches to DSM, including education, electronic monitoring devices, and changes in energy prices or price signaling[4]. One approach to price signaling is to employ interval meters that can measure and record energy consumption at specific times throughout the day. These meters allow the energy supplier to charge higher prices at times of high system-wide (i.e., peak) consumption when energy is generated from expensive fuel sources; the objective of this price signal is to encourage the consumer to reduce consumption during these periods (Matsukawa, 2004).

Despite the potential benefits associated with interval meters, some energy suppliers and their customers are resistant to adopting these meters, due to their higher cost. The widely used alternative, induction meters that simply record total energy consumption, when coupled with a flat rate model (applying the same price per unit of energy to all energy consumed), are not conducive to DSM programs, can result in some customers cross-subsidizing others, and do not address the problem of peak consumption. However, other rate models, such as the inverted block rate, can overcome the limitations of the flat rate model while still using induction meters.

[4] A price signal is a message sent to customers in the form of a price charged for a commodity. The change in price is usually intended to produce a particular result (EEA, 2004).

2 Rate Models

Although the price of a unit of energy paid by a customer depends upon the customer class and rate model, the basic rate model equation is (Skrotzki, 1990):

$$y = dx + ez + c$$

where, for each billing period during which energy was consumed:

y – total amount of bill (e.g., dollars).

d – unit charge for maximum demand (e.g., dollars/kilowatt).

x – maximum demand (e.g., kilowatts).

e – unit charge (or price) for energy (e.g., dollars/kilowatt-hour).

z – total energy consumed (e.g., kilowatt-hours).

c – constant charge (e.g., dollars).

In order to bill a customer, it is necessary to have metering equipment that can measure and record the maximum demand, *x*, or the total energy consumed, *z*, or both.

Rate models such as Hopkinson, Doherty, Wright, and real-time-usage (Seeto, 1997, Skrotzki, 1990), all require interval timers that can measure both demand and energy consumption over given periods of time. With the demand and energy consumption known, these rate models allow the energy supplier to create a variety of price signals, ideally making the price cost reflective.

Time-of-use meters can also measure intervals, although in most applications only energy and the time the energy is consumed are recorded. In these cases, the total charge is a variation on the above equation:

$$y = \sum e_t z_t + c$$

where e_t is the price of a unit of energy and z_t is the total energy consumed, at time interval *t*. These rate models allow the energy supplier to vary the rate based upon the season, day-of-week, or time-of-day, once again, potentially becoming cost reflective. This rate model can incorporate price signals that are intended to encourage various consumption patterns by applying different rates at different times.

Arguably the simplest rate model is the flat rate model[5] using induction-type electricity meters[6] that record energy consumption only (Honeywell, 2004), making the rate equation:

$$y = ez + c$$

This model is widely used by energy suppliers when billing their residential customers. The model is easily understood by customers as it applies a known price, *e*, to a given amount of energy, *z*. The charge, *c*, allows the energy supplier to recover miscellaneous expenses.

3 Flat rate

The flat rate's simplicity belies a number of limitations, notably:

- It restricts the energy supplier's ability to create meaningful price signals.
- It can result in cross-subsidies from customers with demands that are not peak-coincident to those with demands that are peak-coincident.

3.1 Price signals

In the flat rate, all customers pay the same price for a unit of energy, regardless of consumption. With only a single price, the energy supplier has few means available to influence customers' consumption patterns. Any change in price affects all customers; for example, raising rates to discourage consumption impacts all customers, including those with existing low levels of consumption.

3.2 Cross-subsidies

The cost of energy generation varies by season, day-of-the-week, and the time-of-day. In periods of low demand (usually midnight to 6:00am), when most, if not

[5] The flat rate is also referred to as uniform rate, straight meter rate, and single rate.

[6] Also known as Ferraris meters.

all, demand is met by baseload generation, the cost of generating a unit of energy is typically the lowest. On the other hand, when demand is high (often in the early evening), it is necessary to operate more expensive peaking units, resulting in the highest cost for energy generation.

Since the flat rate charges a customer only for the energy consumed, not the demand, the unit price must be a 'blend' of the different costs of generation. The flat rate model implies that all customers exhibit the same consumption profile; put another way, a customer's energy consumption is assumed to be proportional to the demand they put on the system (IPRT, 2004).

Experience shows this is not always the case: a customer's maximum demand is not necessarily coincident with the system peak, meaning that the cost of generation can vary between customers. For example, consider two customers in the same rate class paying the same price per unit of energy, with one consuming 240 units of electricity a day, and the other consuming 660 units. The customer's hourly demand throughout the day is shown in Figure 1, where the first customer's demand is a constant 10 units per hour, whereas the second customer's demand is also 10 units per hour until the late afternoon, when it rises to 60 units. The non-peak demand is 20 units (split evenly between the two customers), while the peak demand is 70 units (10 units for the first customer and 60 units for the second) occurring between 17:00 and 19:00.

The customer's price per unit of energy is obtained, in part, from the costs associated with the different types of generation. If the energy supplier meets the non-peak demand with low-cost, base-load energy and the system peak with a combination of base-load and expensive peak load energy, the price per unit of energy must be a combination of the two. Although both customers pay the same price per unit of energy, the first customer pays disproportionately more per unit because the second customer consumes more energy generated during the (expensive) system peak. In short, one finds that:

- Customers with a large portion of their demand that is not coincident with the system peak are overcharged for the price of a unit of energy.

- Customers with a large portion of their demand that is coincident with the system peak are undercharged for the price of a unit of energy.

In other words, the flat rate structure does not reflect the cost of generation and can result in cross-subsidies. The effect of this on customers is highlighted in Table 1.

Table 1: Potential cross-subsidy effect of the flat rate model
(from IPRT, 2004)

	Demand during system peak	
	Disproportionately lower	Disproportionately higher
Small customer	Paying too much	Paying too little
Large customer	Paying too much	Paying too little

4 Alternatives to the flat rate

Although induction-type meters remain in widespread use because they are inexpensive, energy suppliers with these meters are not restricted to using the flat rate model for determining customer rates. Other rate models are available, notably the step meter rate and the block meter rate (Skrotzki, 1990).

The step meter rate charges customers using a 'sliding scale', where the rate is determined by the energy usage; for example:

$$y = e_1z_1 + c \quad \text{where } 0 \le z_1 \le p$$
$$y = e_2z_2 + c \quad \text{where } p < z_2 \le q$$
$$y = e_3z_3 + c \quad \text{where } q < z_3 \le r$$

where 0, p, q, and r are the energy consumption limits; z_1, z_2, and z_3 are the customer's consumptions; and e_1, e_2, and e_3 are the prices for different levels of consumption. The step meter rate, as originally envisaged (see below), exhibits problems at the energy consumption limits: a customer with energy consumption slightly below a limit may gain significant savings simply by increasing consumption slightly above the limit. The step rate model can be modified to handle this problem, at the expense of added complexity.

The block meter rate divides a customer's total energy consumption into one or more blocks, with each block assigned its own price.

In the block meter rate, the total energy consumption, z, is divided into blocks, where:

$$z = z_1 + z_2 + \ldots + z_n$$

Each block is assigned its own price: $e_1, e_2, \ldots, e_n$. The block meter rate can then be expressed as:

$$y = e_1 z_1 + e_2 z_2 + \ldots + e_n z_n + c$$

For example, if a customer's energy consumption, z, fell into the second block, the total charge would be (note that in this case, $z = z_1 + z_2$):

$$y = e_1 z_1 + e_2 z_2 + c$$

In the block meter rate, the customer's bill is created by dividing the consumption into a series of blocks and then applying a price to each block, while in the step meter rate, a single price is applied to the customer's total energy consumption, depending upon the level of consumption.

Both the step and the block meter rates were originally designed to work with declining prices; that is, the more energy consumed by a customer, the less the price per unit of energy (in other words, $e_n > e_{n+1}$). Declining energy prices are intended to reflect the fact that increased generation spreads the fixed charges over a greater number of units of energy, meaning that the price of energy should decrease as consumption increases (Skrotzki, 1990). With rising fuel prices and growing environmental concerns over the ways in which electricity is generated, many people are questioning the wisdom of creating price signals that encourage the consumption of energy.

5 The Inverted Block Rate

Block rates need not have a declining price structure; if the block rate increases with increasing energy consumption (that is, $e_n < e_{n+1}$), the block rate is said to be inverted[7]. The inverted block rate is different from the flat rate in that it allows the energy supplier to introduce price signals, rewarding customers for reducing consumption and reducing the impact of cross-subsidies.

5.1 Creating an inverted block rate

Energy suppliers must develop rate structures that generate sufficient revenues to recover costs and give a satisfactory rate of return. When developing a rate structure for an inverted block rate for a given customer class, the energy supplier must determine:

- The revenue to be generated from the customer class.
- The number of blocks.
- The energy consumption limits associated with each block.
- The price associated with each block.

The selection of the blocks, the limits, and the prices allows the energy supplier to employ price signals that can encourage changes to customer energy consumption habits.

The number of blocks chosen can have an impact on the rate structure, its usefulness, and possible acceptance:

- An *n*-block structure has *n-1* limits. A block's limit indicates the maximum energy consumption for the block. The tail block[8] has no limit.

  Each block is associated with one or more customers. The first block contains all customers. Block *n* contains the customers with consumption greater than block *n-1*'s limit.

[7] Inverted block rates are also referred to as increasing block rates and inclining block rates.

[8] A tail block is the last block in a block rate structure (inverted or declining).

- A single block is simply a flat rate model in which there is a single price per unit of energy that is common to all customers and, being only one block, there is no upper limit.
- Unless care is taken, the blocks and limits can be manipulated to produce results similar to the flat rate. For example, in a two block structure (i.e., with a single limit), the limit could be put very low (with few customers below the limit) or very high (with few customers above the limit). In either case, it means that most customers pay the same price per unit of energy.

The creation of an inverted block rate structure can be an iterative process:

1. Select the number of blocks.
2. Assign consumption limits to each block.
3. Assign prices to each block.
4. Calculate the revenue from a database of customer energy consumption.
5. If the calculated revenue is not equal to the required revenue, repeat from step 1 (to change the number of blocks), or step 2 (to change the consumption limits), or step 3 (to change the prices).

5.2 Application of the inverted block rate

As an example, consider an inverted block rate consisting of three blocks: the blocks and their associated prices are shown in Table 2.

Table 2: Sample inverted block rate

Block	Price ($/unit)
0 to 2,000 units	0.09
2,001 to 4,000 units	0.10
Greater than 4,000 units	0.11

Three customers consume 1,500 units, 2,500 units, and 4,500 units respectively. The consumption breakdown (by block) and charges associated with each customer are shown in Table 3. Note that all customers are charged by energy consumption per block, meaning that as a customer's energy consumption increases, the price per unit of energy increases (conversely, the less consumed, the lower the price per unit of energy).

Table 3: Consumption breakdown and charges

Customer consumption	**Block 1** ($0.09/unit)	**Block 2** ($0.10/unit)	**Block 3** ($0.11/unit)	**Total charges**	**Price/unit**
1,500	1,500	0	0	$135.00	$0.090
2,500	2,000	500	0	$230.00	$0.092
4,500	2,000	2,000	500	$435.00	$0.097

5.3 Discussion

The inverted block rate offers a number of advantages over the flat rate, including:

- Price signaling. The inverted block rate allows the energy supplier to introduce price signals: low consumption customers have less of an incentive to increase consumption as this leads to a higher price per unit of energy, while high consumption customers have an incentive to decrease consumption as this leads to a lower price per unit of energy.
- Same metering technology. Both the inverted block rate and the flat rate can use induction-type meters. This means that the energy supplier is not required to purchase new metering equipment and that existing meter-reading technology can still be used. The only change required by the energy supplier is in the billing software, as the data obtained from the meter (i.e., the record of the customer's energy consumption during the billing period) remains unchanged.
- Cross-subsidies. In the discussion on the flat-rate model, it was shown that cross-subsidization could occur as customers with demands that are not coincident with the system peak are overcharged for the price of a unit of energy, while those with demands that are coincident can be undercharged.

  By introducing the inverted block rate structure, customers with small energy consumption requirements would be paying less, while those with large energy consumption requirements would be paying more. The shaded areas in Table 4 show those customers for whom these changes come closer to being cost reflective (i.e., the costs reflect the relationship between demand and energy consumption). Some energy suppliers report a strong correlation between large consumption customers and higher system demand, meaning that these price shifts are cost reflective (IPRT, 2004).

Table 4: Impact of inverted block rate

	Demand during system peak: Disproportionately lower	Demand during system peak: Disproportionately higher
Small customer	Lower charges	Lower charges
Large customer	Higher charges	Higher charges

The impact on customers outside the shaded areas in Table 4 shows a movement in the wrong direction, in that small customers with disproportionately large demands should not have lower charges and large customers with disproportionately lower demands should not have higher charges. In these cases, it is necessary to determine how many customers fall into these categories: if most customers are found in the shaded areas of Table 4, then the issue can probably be ignored. However, if significant numbers of large consumption customers have demand outside the peak, then it is worth considering shifting these customers to a different rate class (for example, time-of-day billing).

Similarly, low- or fixed-income customers with high energy consumption[9] may be subject to higher charges in an inverted block rate environment. There are a number of ways in which these customers can be assisted, including changing their rate class or addressing their energy consumption patterns (Indeco, 2004).

[9] These customers are typically users relying heavily on air conditioning for seasonal cooling or electric heating for seasonal heating.

The result of replacing a flat rate model with an inverted block rate model is that rates become more cost reflective for:

- Small customers with a large portion of their demand that is not coincident with the system peak.
- Large customers with a large portion of their demand that is coincident with the system peak.

Although the inverted block rate allows price signaling and reduces the impact of cross-subsidies, it does not have a time component, meaning that (like the flat rate), there is no incentive for customers to shift their demand from the system peak. To be successful, an inverted block rate program requires the energy supplier to educate customers of the benefits of lifestyle changes that can result in decreases in the price per unit of energy.

5.4 Examples

Although the basic tenet of the inverted block rate, “use more, pay more”, may appear to be the antithesis of most modern consumer societies, it does not mean that the inverted block rate is not in use. In fact, the inverted block rate is widely used, notably in settings where there is a need to limit consumption of a valued resource, such as water.

In parts of the United States, the availability and supply of potable water has become a problem because of falling water tables, growing populations, lack of freshwater supplies, and increased environmental awareness (Postel, 1992). The inverted block rate model has been identified by public utilities as a means of sending a water conservation signal to consumers through increased prices for increased usage (City of Boulder, 2004).

Until recently, inverted block rates have not been widely adopted by electrical energy suppliers in North America (Tedesco, 2004). A possible reason for this is that few energy suppliers have looked upon electricity as a resource worth conserving, as growth rather than conservation has been the driving force behind most energy suppliers (Patterson, 1999). This view is changing as energy suppliers are facing the prospect of replacing aging generating facilities, increasing fuel prices, and growing environmental concerns (Golby, 2004).

Inverted block rates have been used in California since 2001, where the California Public Utilities Commission imposed a five-tier inverted block rate to encourage energy conservation. The blocks consist of a “baseline” (determined by the customer’s energy requirements), then increasing percentages of the baseline (101 to 130 percent, 131 to 200 percent, 201 to 300 percent, and finally, greater than 300 percent). Southern California Edison’s price per unit energy per block ranges from 13.009 cents per kilowatt-hour (lowest block) to 25.993 cents per kilowatt-hour (highest block) (SCE, 2004).

In Vermont, the Burlington Electric Department has a two-block inverted block rate for residential customers: the first 200 kWh are charged 5.945 cents per kilowatt-hour, while the tail-block is charged 10.1427 (summer) or 10.5309 (winter) cents per kilowatt-hour (BED, 2003).

Another example of inverted block rates are the ‘lifeline’ rates which charge a rate lower than the residential flat rate to low- and fixed; income individuals and families for a limited number of kilowatt-hours per year (Colton, 1995). The reason for such programs can be illustrated by a recent study from Ontario which found that the lowest earning 20 percent of the population spends up to five times the relative amount of their income on water, energy, and electricity as does the highest earning 20 percent (Indeco, 2004).

6 Example

Nova Scotia Power Incorporated (NSPI) is an investor-owned, regulated public utility, and is the primary electricity supplier in the Canadian province of Nova Scotia (Emera, 2004). NSPI owns 2,243 megawatts (MW) of generating capacity: 55 percent is coal-fired; oil and natural gas fired facilities together comprise another 27 percent of capacity; while renewables (hydro-electric and wind) provide the remaining 8 percent. Of the 12,329 GWh produced in 2003, 75 percent was from coal, 12.5 percent was from oil, 9 percent was from renewables (primarily hydro-electric), and the remainder was from natural gas and interprovincial purchases.

6.1 NSPI's residential rate

NSPI has two residential rate structures[10] (NSPI, 2004):

Domestic Service Tariff. The flat rate, with an energy charge of 8.61 cents per kilowatt-hour[11] and a monthly customer charge of $10.83 per month. The flat rate tariff is used by over 99 percent of Nova Scotia Power's residential customers. About one-quarter of residential customers use electric heating (Emera, 2004).

Domestic Service Time-Of-Day Tariff. An optional time-of-use rate, intended for residential customers with electric thermal storage (ETS) heaters. The price varies from an overnight (11:00pm to 07:00am) low of 4.305 cents per kilowatt-hour to a morning and evening peak price of 12.37 cents per kilowatt-hour. The prices also vary by season: "winter" (December, January, and February) and "non-winter" (March through November), with the system peak usually occurring during the "winter". Afternoon weekday "winter" charges and all-day and evening "non-winter" charges are equivalent to the residential flat rate price (8.61 cents per kilowatt-hour). In 2003, there were about 3,000 Time-Of-Day tariff customers (Emera, 2004).

In 2003, there were 418,931 Domestic Service Rate (residential) customers with a total energy consumption of about 3.94 gigawatt-hours. Each customer's annual energy consumption averaged about 9,400 kilowatt-hours[12].

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[10] NSPI actually has a third residential rate structure, an optional block rate for their Green Power Rider. Residential customers who subscribe to the program pay $5.00 per month for each 125 kilowatt-hour block of 'green power' (or 4 cents per kilowatt-hour) *plus* the Domestic Service Tariff (presently 8.61 cents per kilowatt-hour) for a total of 12.61 cents per kilowatt-hour. The first 125 kilowatt-hours of energy used per month is assumed to come from a green power source. The Green Power Rider, introduced in 2003, has met with limited public acceptance.

[11] Unless otherwise indicated, all prices are in Canadian dollars.

[12] These and subsequent figures are taken from NSPI's 2003 Domestic Service Rate data. The data was supplied to the author in response to an information request regarding NSPI's proposed

Figure 2 shows the annual energy consumption in terms of the number of customers; some observations from this Figure include:

- Lowest energy demand: 6,704 customers consumed less than 100 kilowatt-hours.
- Highest energy demand: one customer consumed 1,634,880 kilowatt-hours.
- 99 percent of customers consume less than 36,000 kilowatt-hours per year.

In order to gain an understanding of the distribution of residential customers and their energy consumption, the NSPI data is examined, first in terms of customers and second, in terms of energy consumption. In both cases, the data is divided into quintile-groups[13].

Figure 3 shows the energy consumption per customer quintile-group. Each quintile-group represents one-fifth of the total residential customer base or 83,786 customers. The consumed kilowatt-hours, the percentage of residential energy consumption, average kilowatt-hours, and the quintiles are listed in Table 5.

Table 5: Customer quintile-groups

Quintile group	**Consumed kWh**	**Percentage of residential consumption**	**Average kWh**	**Quintile** (kWh)
1	137,354,326	3.48%	1,639	3,400
2	397,083,031	10.07%	4,739	6,300
3	630,272,845	15.99%	7,522	9,100
4	953,057,741	24.18%	11,375	14,000
5	1,823,690,416	46.27%	21,766	

2004 rate increase. The data is organized into blocks of 100 kilowatt-hours, with each block consisting of: the lower and upper bound of each block, the number of customers in the block, and the total energy consumption of the customers in the block. For example, the eleventh block contained data on the 2,056 customers who use between 1,000 and 1,100 kilowatt-hours per year; the total energy consumption for this block was 2,099,431 kilowatt-hours. The data contains numerous discrepancies, such as the average consumption for a block being less than the block's lower bound.

[13] Quintiles are values which divide a population into five equal sized "quintile-groups"; there are four *quintiles*. The first quintile divides the first and second quintile-groups. The lowest quintile-group is the bottom 20 percent of the population, while the highest quintile-group is the top 20 percent of the population.

Table 5 highlights a number of points regarding residential energy consumption:

- The lowest quintile-group consumed about 137 million kilowatt-hours, an average of 1,639 kilowatt-hours per consumer.
- The highest quintile-group consumed about 1,824 million kilowatt-hours, an average of 21,766 kilowatt-hours per customer.
- The maximum consumption of the lowest three quintile-groups (9,100 kilowatt-hours) is less than the overall residential customer average of 9,400 kilowatt-hours.
- A customer in the lowest quintile-group has an average energy consumption which is about one-thirteenth that of the highest quintile-group's average energy consumption.

Figure 4 divides customers into energy consumption quintile-groups of approximately 788 million kilowatt-hours per group. Table 6 summarizes the energy consumption quintile-groups.

Table 6: Energy consumption quintile-groups

Quintile group	Number of customers	Percentage of customers	Maximum kWh
1	199,997	47.74%	7,400
2	89,128	21.28%	10,900
3	62,468	14.91%	15,700
4	42,222	10.08%	23,000
5	25,116	6.00%	1,643,900

The following observations can be made from the energy-consumption data:

- Almost half NSPI's residential customers (199,997 customers in the first quintile-group) are responsible for about one-fifth of the residential energy consumption.

- The highest quintile-group has the least number of customers (25,116) and the widest distribution of consumption (14,000 kilowatt-hours to 1.64 million kilowatt-hours).
- The lowest quintile-group has about eight times the number of customers found in the highest quintile-group.

6.2 An inverted block rate

NSPI's existing flat rate Domestic Service Tariff charges 8.61 cents per kilowatt-hour for energy consumption. Early in 2004, NSPI announced that it would apply to the provincial utility board for a rate increase of 10.22 percent, raising the Domestic Service Tariff to 9.49 cents per kilowatt-hour. Given the limitations associated with the flat rate and the potential impact such an increase would have on low- and fixed-income Nova Scotians, the author decided to examine the implications of replacing the existing flat rate Domestic Service Tariff with an inverted block rate.

As discussed in section 5.1, there are four issues that must be addressed when developing an inverted block rate structure:

- The revenue to be generated from the customer class.

  Changing the billing scheme from the existing flat rate to the inverted block rate should be revenue neutral, meaning that NSPI should neither make a profit nor suffer a loss in revenue because of the changes in the billing model.

  In 2003, NSPI's billed energy sales amounted to 3,941,458,359 kilowatt-hours. Applying the proposed new price of 9.49 cents per kilowatt-hour to the 2003 sales would generate a flat rate revenue of $374,044,398. The revenue from any inverted block rate should equal this amount.

- The number of blocks.

  The proposed rate is divided into five blocks: energy from the lowest (block 1) is consumed by all customers, while energy from the tail (highest) block (block 5) is consumed by the smallest number of customers. To make it easier to refer to the results found in the analysis of NSPI's data, the blocks correspond to the customer quintile-groups shown in Table 5.

- The limits associated with each block.

  The limits associated with each block are the quintiles obtained from the NSPI data presented in Table 5. The resulting distribution of energy consumption by block is shown in Figure 5, while the relationship between the blocks, customer quintile-groups, and consumption per block is shown in Table 7.

Table 7: Energy consumption breakdown by block

Block	**Limits** (kWh)	**Customer Quintile-groups**	**Total consumption** (kWh)
1	3,400	1, 2, 3, 4, 5	1,276,971,748
2	6,300	2, 3, 4, 5	851,447,294
3	9,100	3, 4, 5	582,858,750
4	14,000	4, 5	584,479,202
5		5	645,701,365

The total consumption for each block is obtained by summing the quintile-group consumptions up to each block's limit. The consumptions for each quintile-group are then reduced by this amount. The total consumption of the tail block represented about 16 percent of the overall residential energy consumption; this reflects the distribution of consumption in NSPI's residential customer class.

- The price associated with each block.

  Since obtaining the final rate structure is an iterative process, it is necessary to make an initial selection, assigning a price to each block. In this example, the median block (block 3) is assigned a price equal to the flat rate price, 9.49 cents per kilowatt-hour (0.0949 dollars per kilowatt-hour); the assignment of the other prices are a percentage of the median block and shown in Table 8.

Table 8: Initial price assignment

Block	**1**	**2**	**3**	**4**	**5**
Change from median block	-10%	-5%	0%	+5%	+10%
Price ($/kWh)	0.08541	0.09015	0.09490	0.09964	0.10439

With the total consumption per block known, it is a simple matter to determine the total revenue. The revenue generated using the initial block rates (from Table 8) is $366,786,879 (see Table 9), which is $7,257,520 less than the revenue obtained from the flat rate.

Table 9: First iteration of inverted block rate revenue

Block	**Consumption** (kWh)	**Price** ($/kWh)	**Revenue** ($)
1	1,276,971,748	0.08541	$109,190,009
2	851,447,294	0.09015	$76,762,231
3	582,858,750	0.09490	$55,313,295
4	584,479,202	0.09964	$58,240,430
5	645,701,365	0.10439	$67,404,765
Totals	*3,941,458,359*		*$366,786,879*

Since the revenue falls short of the target, it is necessary to determine new prices that will increase the revenue. This can be done in a number of ways; for example, each block's price can be examined in turn, adjusted, and the new total calculated and compared with the target revenue. Another approach is to increase each block's price by the reciprocal of the percentage difference between the revenue generated and the target. In the above example, the shortfall is about two percent; increasing each price by the reciprocal of this amount effectively eliminates the shortfall, as shown in Table 10.

Table 10: Revenue with new block rates

Block	**Consumption** (kWh)	**Rate** ($/kWh)	**Rate Increase**	**Revenue** ($)
1	1,276,971,748	0.08710	1.16%	$111,224,222
2	851,447,294	0.09194	6.78%	$78,281,106
3	582,858,750	0.09678	12.40%	$56,407,766
4	584,479,202	0.10162	18.02%	$59,392,819
5	645,701,365	0.10646	23.64%	$68,738,487
Totals	*3,941,458,359*			*$374,044,398*

6.3 Discussion

One argument against changing from the flat rate model to the inverted block rate model is that by having one or more of blocks with prices per unit of energy less than the existing flat rate, customers with consumptions in a lower block would use more as there would be no incentive to consume less energy (Neufeld, 1981).

Although this argument may be true in some circumstances, in the example presented in this section, the 167,572 customers with energy consumptions that do not exceed the limit's of the first two blocks (i.e., below 6,300 kilowatt-hours per year) would see maximum increases of 1.16 percent (8.61 cents per kilowatt-hour to 8.71 cents per kilowatt-hour) and 6.78 percent (8.61 cents per kilowatt-hour to 9.19 cents per kilowatt-hour), respectively. Low- or fixed-income consumers whose consumption falls into these two blocks are unlikely to consume more energy (up to the block's limit) simply because the price per unit of energy is less than that of the next block (Power, 2001).

Another argument against this rate structure, put forward by the CEO of NSPI, is that in an inverted block rate environment, high-consumption, efficient energy consumers cross-subsidize inefficient consumers (Tedesco, 2004). As shown in section 5.3, this depends entirely upon the individual customer demands: in some cases it may be true; however, in others it may not. Without the availability of NSPI's residential demand data, it is impossible to judge the merits of this argument. Furthermore, this can hardly be used as justification for maintaining the flat rate model.

A third argument against inverted block rates is the impact of the rate structure on high-consumption, low-income customers. These customers are typically users of electric-heating. One solution to this problem is to shift the customers to the time-of-day rate structure, which is intended for users of electric heating.

For the proposed inverted rate structure to succeed, it is necessary to ensure that customers are fully aware of the benefits of the program (notably, a reduction in the cost per unit energy and a reduction in cross-subsidies). The new structure would have to be introduced with an ongoing education campaign. Part of the campaign would include a breakdown of the energy prices in terms of each block and the resulting price per kilowatt-hour as part of each customer's bill. This type of information would allow customers to see the financial benefits of reducing their consumption.

6.4 Impacts on revenue

Some of the possible impacts of the proposed inverted block rate on energy consumption and revenues are presented in Table 11 (the percentage change is applied to all customers).

The rate of change in revenue depends upon whether the consumption increases or decreases: when using the inverted block rate structure, an increase in consumption favours the energy supplier over the customers, whereas a decrease in consumption favours the customers over the energy supplier. This should not be surprising, as an increase in consumption pushes customers into the next higher block (or drops them into lower blocks if consumption decreases).

Table 11: Impact of consumption changes

Change	**Consumption** (kWh)	**Flat Rate Revenue**	**Inverted Block Rate Revenue**
+1.0%	3,980,872,942	$377,784,842	$378,047,387
+0.5%	3,961,165,650	$375,914,620	$376,045,635
0.0%	3,941,458,359	$374,044,398	$374,044,398
-0.5%	3,921,751,067	$372,174,176	$372,044,175
-1.0%	3,902,043,775	$370,303,954	$370,044,632
-2.0%	3,862,629,191	$366,563,510	$366,047,212
-5.0%	3,744,385,441	$355,342,178	$354,072,616

The differences in revenue between the flat rate and inverted block rate are clearly negligible. However, of the two rate structures, the inverted block rate is preferable, as it allows price signaling and can reduce cross-subsidization.

7 Concluding Remarks

In order to recover certain costs and have a competitive return on investment, energy suppliers must bill their customers. How the bill is determined depends upon each customer's rate class and the type of metering available. Meters that measure both demand and energy allow a wide range of billing strategies, whereas those restricted to measuring energy consumption have typically been used in flat rate models.

Although the flat rate model is simple and easily understood by customers, it is not cost reflective: energy consumption and system demand are not necessarily proportional. Customers with demands that are not coincident with the system peak can subsidize customers with coincident demands. Since large consumption customers often have higher coincident demand, this can result in low- and fixed-income customers cross-subsidizing large consumption customers. An alternative to the flat rate model is the inverted block rate model, in which each customer's energy consumption is divided into blocks, with each block assigned an increasing price per unit energy.

As well as using the same metering equipment as the flat rate, the inverted block rate:

- Allows price signaling by increasing the price per unit of energy for each block. Low consumption customers are discouraged from increasing consumption as this leads to higher prices per unit of energy, while high consumption customers are encouraged to decrease consumption as this leads to lower prices per unit of energy.
- Reduces or eliminates cross-subsidies for customers with low energy consumption and disproportionately lower demand during the system peak.

An argument put forward against adopting the inverted block rate is that lower energy prices can encourage customers to increase their energy consumption. In a time of rising energy prices, this argument breaks down as customers begin to look for ways to reduce their costs. If customers are aware that the price per unit of energy declines with decreasing energy consumption, they will look for ways to reduce consumption. Conversely, if they are aware that the price of a unit of energy increases with increased consumption, there will be no incentive to increase consumption.

Another argument against the inverted block rate is that it penalizes customers with high consumption by making their overall bill greater than it would be in a flat rate environment. This argument can be addressed in two ways. First, by reducing demand, both consumption and price per unit of energy decline. Second, if this becomes a serious issue for customers with high energy consumption, the energy supplier can create a new rate class for these customers.

To be successful, an energy supplier's inverted block rate structure should have:

- Sufficient blocks to encourage changes in consumption patterns.
- An educational component, explaining the benefits of the structure to customers.

In short, the inverted block rate model is superior to the flat rate model since it allows the use of price signals, can reduce cross-subsidies, and can reduce the impact of price rises on low- and fixed-income customers.

Energy suppliers that can afford to supply all customers with interval timers that can record energy consumption (and possibly demand) should do so, as this will allow billing that is more cost reflective. Until then, customers whose energy consumption is recorded by induction meters should be billed according to an inverted block rate model, as it can be cost reflective and encourage the efficient use of energy, something the existing flat rate structure cannot do.

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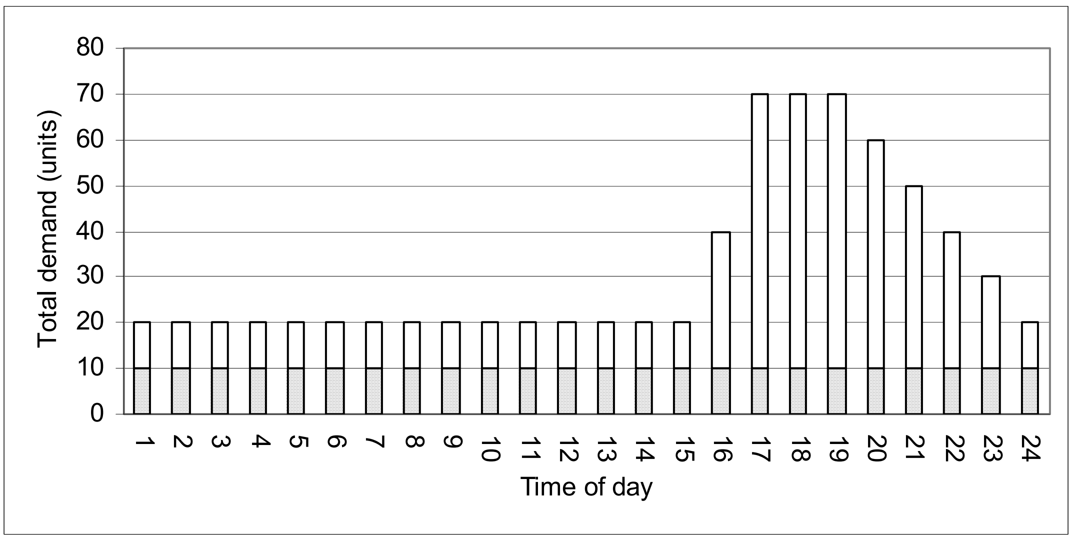

Figure 1: Potential for cross-subsidies in the flat rate model

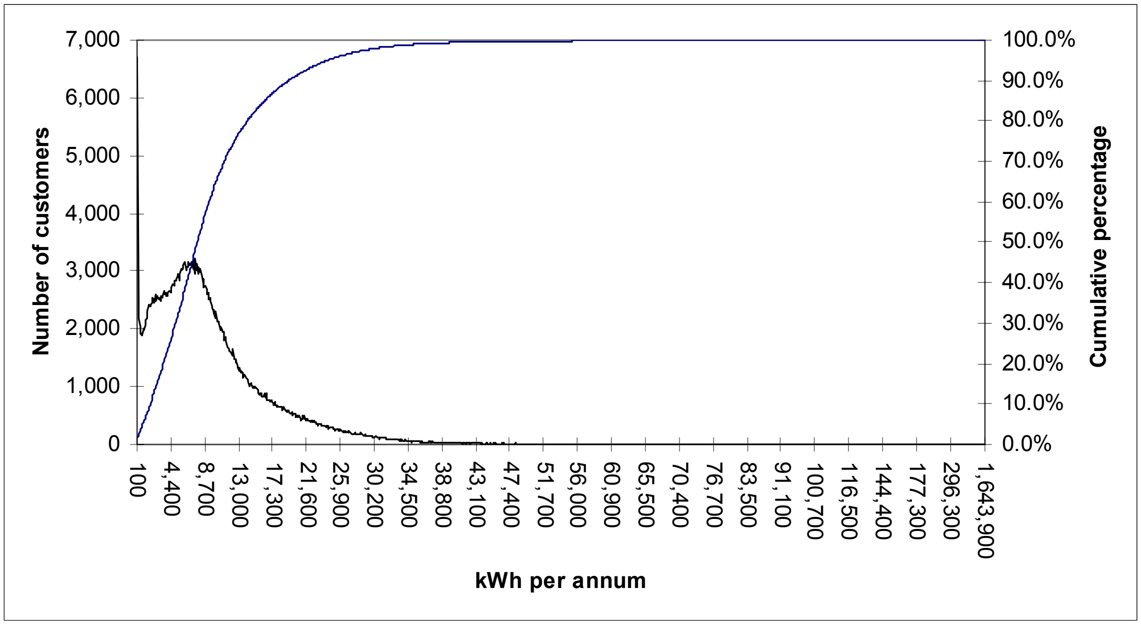

Figure 2: Annual energy consumption

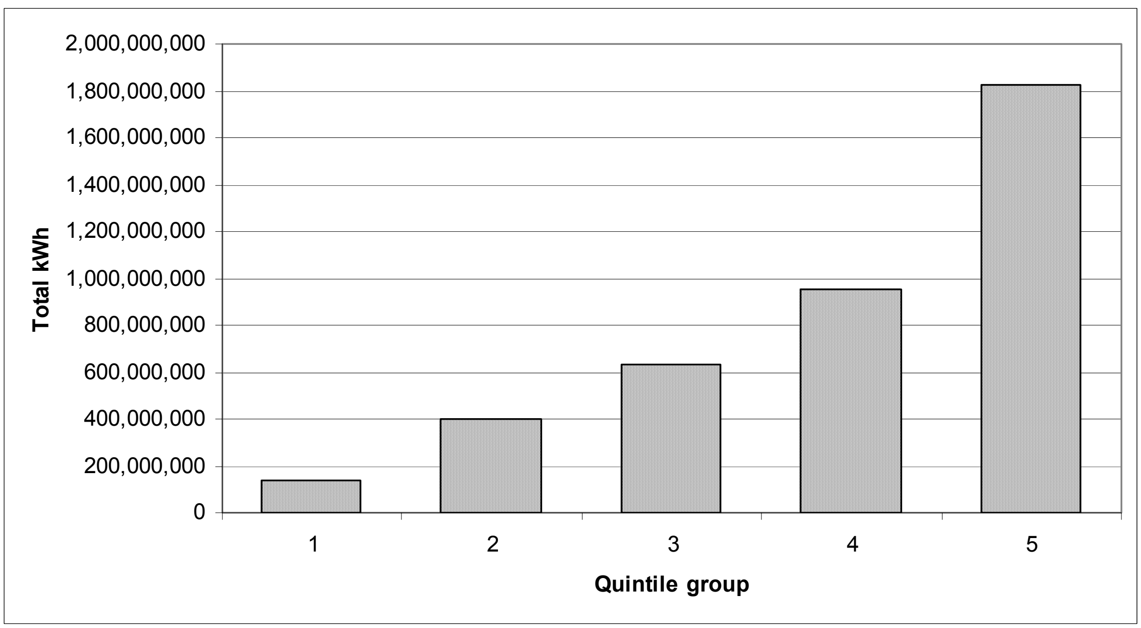

Figure 3: Energy usage per customer quintile-group

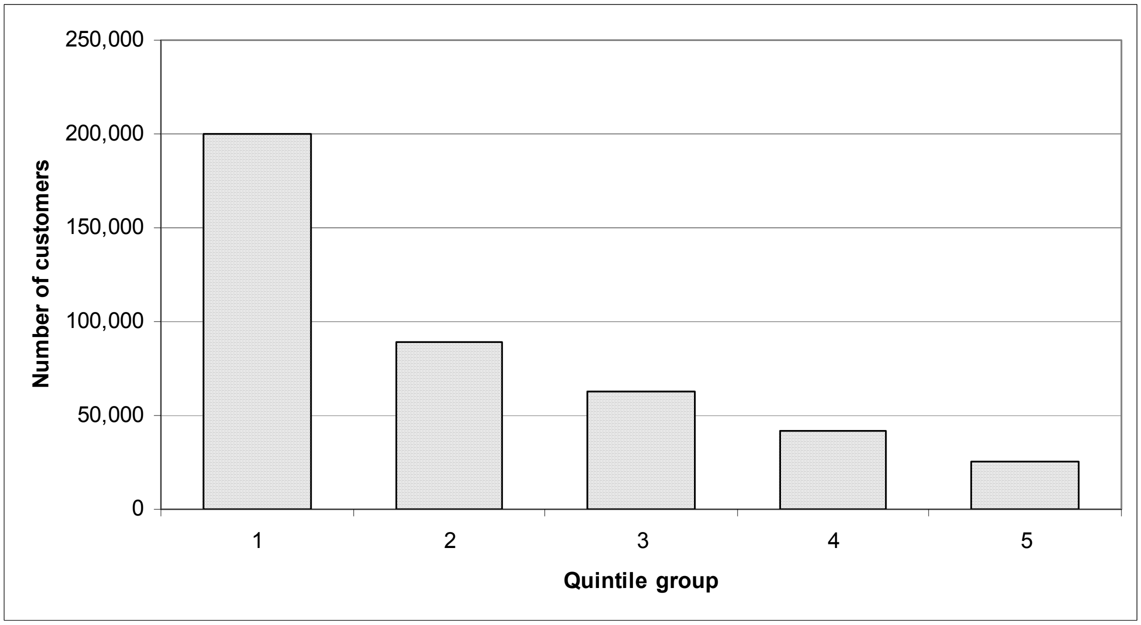

Figure 4: Number of customers per energy quintile-group

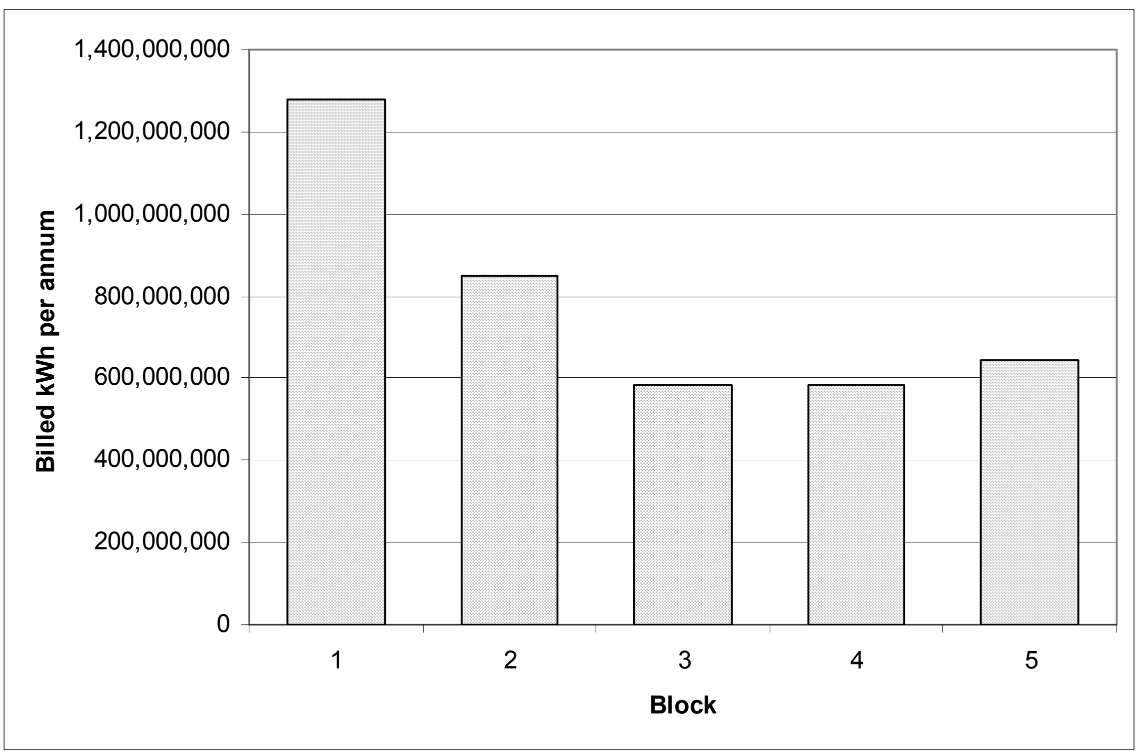

Figure 5: Energy consumption (kilowatt-hours) per block