Price Normalization to Facilitate Energy Efficiency—Algorithms and Issues

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Abstract

One of the key DR applications involves the use of smart appliances and devices within a facility (residential or small commercial buildings) that can be programmed and automated to respond to DR signals (that could be either pricing signals or other energy curtailment signals) arriving from a utility, wholesale market, or a 3rd party energy service providers. Several technical, business, and policy challenges need to be overcome before such DR applications become ubiquitous and gain widespread consumer acceptance.

In this paper we concentrate on the abstraction of dynamic prices to Simple Levels, and propose metrics for quality of mappings. We also address general issues with mapping including volatility, seasonal variation, and effective use of Levels where price (hence cost) is abstracted away.

Several significant issues arise in performing price normalization.

1. The general range of prices changes over time—from summer to winter, from year to year.
2. The mapping between price ranges and QoS provided to consumers from various smart devices. Furthermore, these mappings need to consistent among different price providers, software, and/or curtailment requesters.
3. The normalization must express information needed to properly respond to actual price information, and must show differentiation across time

In this paper we examine issues on evaluation of price normalization algorithms, and examine several classes of algorithms, including moving averages, statistical analysis of history, and hybrid approaches. We apply them to sample historical price streams where wholesale prices are used as proxies for retail prices, and compare to actual approaches used in pilot projects

1. INTRODUCTION

The problem of abstracting what we call Simple Levels (or *Normalized Prices*) from real-time price streams seems simple on the surface. The goal is to give a simplification of prices to Energy Managers (EMs) and devices, presuming that their goal of cost-effective energy use and energy conservation is well-served by the simplification.

In effect, the Simple Levels are though to be a "good enough" abstraction of actual price behavior to improve energy efficiency.

In this paper we examine these assumptions, describe and analyze the problem, and propose metrics for the quality of algorithms to define Simple Levels from real-time price streams.

We also discuss the aspect of prediction, and forward- and backward-looking approaches.

2. THE ASSUMPTIONS

There are several explicit and implicit assumptions around Simple Level abstractions. For example, the Smart Energy Profile 2 work requires that a facility system be "[p]rovided a simple, relative price signal (e.g., low, medium, high, critical)" [SEP-MRD] but also wants cost information for the present and historical periods.[1]

We assume that Simple Levels run from 1 to MaxLevels, a parameter that may vary across deployments. SEP2 [SEP2-AS], for example, presumes four levels, but is configured to express more; OASIS Energy Interoperation [EnergyInterop] Simple Levels are parameterized. ISOs that deliver Simple Level information have chosen varying numbers of levels, including 3, 4, 9, and 11 [NEED REFERENCE – RISH?].

Ivan O'Neill says that, "Beyond three or four total relative price levels, additional relative price levels do not provide substantial consumption reduction or load shifting for most residential applications." [O'Neill]

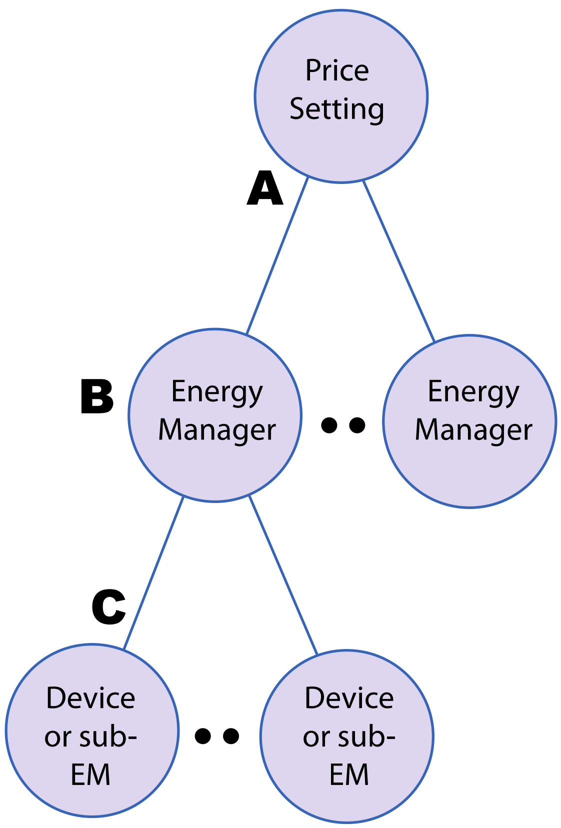

FIGURE 1 WHERE TO DETERMINE SIMPLE LEVELS?

[1] The [SEP-AppSpec] has a parameterized numPriceLevels but appears to require perhaps four levels. (p.104)

In the next sub-sections we list and briefly describe some assumptions.

2.1. Simple Levels Reflect Cost

The most that is reflected in Simple Levels is relative price (or cost). While it's critical to have monotonically increasing prices in parallel with increasing Simple Levels, the steps are not defined in the abstraction. So Simple Levels reflect relative cost as higher or lower, but not how much higher or lower.

2.2. Computing Levels take Significant Resources

It is implicitly assumed that Simple Level computation takes significant computing and/or memory resources. For example, "Price responsive devices require slightly different price signals than nominal price signals; they require *relative price signals* that use metrics such as high, medium, and low to convey the context of the nominal price and drive action." [O'Neill]

The implication is that it is more efficient or cost-effective for something other than the device or the residential EM to compute relative prices.

2.3. EMs want an abstraction of Price

This assumption is connected to the computing resource assumption. If the computation can be done in one place (near the price-setting point) then it's more efficient for the large numbers of EMs and the larger number of devices getting price information.

2.4. Price Responsiveness is "Good Enough" with Simple Levels

This is implicit in the referenced work and others that presume that Simple Levels are all that's required. We'll discuss this in more detail below; suffice it to say that this requires experimental evaluation, not simple assertion.

2.5. The Needs of the Recipient Don't Matter

In effect, one size fits all is the approach. Assuming that price responsiveness is "good enough" together with assuming significant resources for computing levels, we are drawn to conclude that the possibly varying needs of the consumers of Simple Levels don't matter.

3. THE MODEL

We define the Cut Points (or inflection points) for a scheme for [Simple] Levels as follows. We use the terminology in [O'Neill], where the nominal price conveys actual price information and the relative price corresponds to Levels.

The input is Price, which varies over time. We map an input Price(t) into Levels, which are numbered from 1 to

MaxLevels (a parameter that is constant for a given deployment).

There are therefore MaxLevels – 1 Cut Points that separate the set of levels. Figure 2 shows a structure with four Levels and three Cut Points.

We identify $Price_i$, the Price mapped to $Level_i$. This yields the following relationships:

$$Price \leq Price_1 \text{ then } L = 1$$

$$Price_{i-1} \leq Price \leq Price_i \text{ then } L = i$$

$$Price_{MaxLevels-1} \leq Price \text{ then } L = MaxLevels$$

We call these $Price_i$ (i = 1..MaxLevels – 1) numbers Cut Points. See Figure 2.

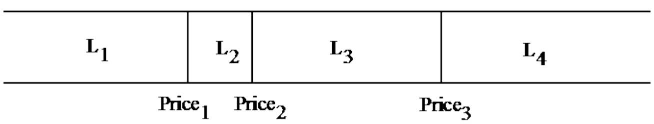

FIGURE 2 CUT POINTS AND [SIMPLE] LEVELS

Of course, Cut Points that work during a time of high prices (say summer in New York) will not work well during a time of low prices (say winter in New York, or any time in Tennessee), so the Cut Points and therefore the Levels change over time as well as geographic location.

The nature of the necessary change over time and prevailing prices, and the quality of abstraction that gives rise to energy and cost efficiency, is the main topic of this paper.

4. THE PROBLEM

We focus on two things:

1. The extent of similarity to actual prices, therefore actual costs
2. A figure of merit that will allow us to compare the quality of adaptive algorithms to determine Cut Points

This will lead to a framework to analyze mapping algorithms.

It's clear that to determine cost for a time interval we need to know the usage during the interval and the (average) price during the period. Since this information is not necessarily conveyed in simple models delivering Levels (e.g.. [SEP2] and [O'Neill]) we suggest that both the Nominal and Relative price be conveyed.

4.1. Approximation to Prices

We know from calculus that a set of rectangles can approximate a curve; Levels are an approximation to a price curve. [[See FIGURE .]] However in typical calculus approaches, the X-axis width of the intervals is the same but the Y-value or height is not constrained (and is usually equal to some value of the function in the interval). Here we observe that the number of Levels, MaxLevels, remains constant, but the Cut Points may vary over time, and that the interval widths may or may not be consistent.

As in [EMIX-early Considine/Cox REF] we focus on actions, and actionable price information. Concentrating on the actions taken, would actions be different with complete knowledge of Price(t) rather than L(t)?

Levels provide a coarse approximation; continuing with four Levels as in Figure 2, the difference between the price in L_1 and L_2 is at least ($Price_3$ – $Price_1$) and is unbounded. We may look for examples of incorrect actions with volatile prices.

It is important to note that wholesale prices tend to be volatile (see [Hirst] where price volatility is used to justify price-responsive demand by separating risk mitigation with commodity pricing; see also [Zareipour] Chapter 5 and [Zareipour2007] which analyze price volatility across wholesale markets). We do not further discuss those results except to note that high volatility suggests relatively worse performance for Simple Levels.

Finally, if price is fixed, as with Time of Use contracts or tariffs, or slightly variable as with Block & Tier contracts or tariffs, it may make sense for the Cut Points to be those of the tariff—but as we have shown elsewhere [EI-SEP] those Cut Points vary from customer to customer and from area to area. Moreover, simple levels convey only a rough approximation of costs, which is critical information in making energy choices.

4.2. Asymmetry

The prevailing price over some period establishes the expected basis for deciding whether electricity is inexpensive, expensive, or "normal." While a consistent change in price (say one cent per kWh) is the same cost differential whether the prevailing price is high or low, the literature suggests that there is greater volatility at higher prices.

Considering a 50 per cent change in price, the economic value or cost is greater at higher prices; this asymmetry may be important in designing mapping algorithms.

Mapping algorithms, to have beneficial economic effect, must respond to changes in the prevailing price—all high or all low Levels may masquerade significant costs.

We suggest [BELOW] that algorithms reflect both longer-term and shorter-term price levels and volatility to address the masquerading issue.

4.3. Quality Metrics

While we work under the assumption that relative price determination is at higher levels (A or B in Figure 1), the figure of merit for a particular dynamic mapping needs to compare results from use of Levels compared to an "equally intelligent" algorithm using actual prices.

We propose that difference in cost of electricity for a given mapping algorithm compared to when optimal choices are made with full knowledge of prices.

We note that devices programmed to take four levels, as input cannot effectively use more levels or full price variation. Accordingly we look rather at the choice of when to perform specific actions.

In Section 5 we address a simple model that permits calculation of cost differences.

5. ANALYSIS

PENDING – notes for some of this

5.1. Model Device Behavior

5.2. An Extended Example of Price Streams

5.3. PNL Algorithm

5.4. Vineyard Project Algorithm

5.5. Moving Average Algorithm

6. SUMMARY AND CONCLUSIONS

We have defined a model for mapping of prices to Simple Levels, and examined the challenges.

Some basic assumptions that have been made in designing residential systems appear to have little foundation in fact; our figure of merit provides a means of evaluation the efficacy of level mapping algorithms, though based on the assumption that the facility EM supports four levels.

Further work will focus on volatility measures, scale and scope of combining general and recent prices, and further refinement of algorithms using our analytic framework.

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Biography

Include a brief biography of no more than 200 words for each author at the end of the article to give it greater impact and validity for the audience.

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