

Optimal Retail Electricity Contracts with Contractible Uncertainty

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Views expressed here are those of the authors and not the views of the ACCC or the AER.

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- A key component of the electricity sector transition is the increasing penetration of local generation, local storage, electric vehicles and so on - connected at the distribution network level.
- There is widespread recognition that we need to move to more dynamic, cost-reflective retail tariffs.
- But there is no consensus on what we should be aiming for. Should we seek time-of-use tariffs, demand charges, critical-peak pricing, or wholesale pass-through? Do we need different tariffs for prosumers? The debates on these issues around the world seem endless.
- This paper seeks to provide a concrete answer to this question in a key special case.

The fundamental question is the following: What is the theoretically-correct design of the retail electricity contract?

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If customers were risk-neutral

- If retail customers were risk-neutral this question would have a very simple answer: We would simply expose every customer to the Locational Marginal Price at his/her location in the distribution network.
- Research in DLMPs is on-going, and several questions remain. I will assume that this problem has been solved and we have a distribution-level wholesale price for each customer.
- In a competitive market, the DLMP reflects the short-run marginal cost of electricity at the location of the customer and therefore provides the right signals for operation of, and investment in, distributed energy resources.
- But retail customers do not behave as though they are risk-neutral – they seem to actively prefer tariff structures which insulate them from risk (such as ‘flat’ retail tariffs).

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How do we design tariffs that both provide efficient price signals *and* insulate customers from risk?

- This paper is, by design, abstract and academic. We make a number of rather strong assumptions. We assume:
 - There exist a wide range of hedging instruments and an effective and liquid hedge market.
 - Retailers can observe the key characteristics of the assets of the retail customers.
 - The factors driving consumption/production (e.g., wind speed) are observable and contractible.
- The idea is to determine the optimal retail contract in an important special case, as a point of reference, and to see what we can learn.

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Highlights

- We show that in the optimal retail contract each customer is exposed to the wholesale spot price at the margin, but, at the same time, each customer is perfectly insulated from risk.
- We show that the hedge contract component of the optimal retail contract is the convex conjugate of the 'value function' and can be arbitrarily-closely approximated using a portfolio of Caps and Floors.
- We confirm that the customer retains the correct incentives to invest in generation and consumption assets.
- We illustrate the operation of this contract using various simple examples.
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The Prosumer

We envisage an electricity market with a large number of 'customers' who may hold some mix of generation, consumption and storage assets which we will refer to as a 'prosumer' or 'customer'.

When the prosumer is (net) extracting from the network at rate q he/she earns value/utility at the rate $V(q, x)$ where x is a vector of factors which affect the consumption or production of the customer, such as the wind-speed, or temperature. $V(q, x)$ is concave in q ($V'(q) \geq 0$, $V''(q) \leq 0$).

$V(q, x)$ reflects the gross consumer's surplus or the gross producer's surplus (which is the cost of production).

There is a local spot price (i.e., the wholesale DLMP at the location of the customer) denoted p .

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The Retail Contract

The customer faces a retail contract given by $R(q, p, x)$, so the customer's net payoff is:

$$\pi(q, p, x) = V(q, x) - R(q, p, x) \quad (1)$$

As an example, the most common retail tariff (a 'flat tariff') takes the form:

$$R(q, p, x) = \begin{cases} \hat{p}q, & \text{if } q > 0, \text{ and} \\ \hat{f}q, & \text{if } q < 0 \end{cases} \quad (2)$$

Here \hat{p} is a flat retail price for consumption and \hat{f} is a flat 'feed-in tariff'. In the case of a 'wholesale pass-through' contract the retail contract takes the form:

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The customer is assumed to have mean-variance preferences. Specifically, the customer is assumed to maximise:

$$E(\pi) - \frac{1}{\beta} \text{Var}(\pi) \quad (4)$$

Here β is a parameter – the larger is β , the closer the customer is to risk neutral.

Mean-variance preferences are not a 'coherent risk measure' but are convenient here because there are no 'income effects'. There is a large literature making use of mean-variance preferences.

For any given retail contract $R(q, p, x)$ there is a corresponding choice of demand/supply curve for the customer $\hat{q}(p, x)$, which maximises the customer's utility (equation 4) for each value of p, x .

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The Optimal Retail Contract - 1

The main result of the paper is as follows. The optimal retail contract takes the following form:

$$R(q, p, x) = pq - H(p, x) \quad (5)$$

Where $H(p, x)$ is the hedge contract component, equal to:

$$H(p, x) = \max_q \{V(q, x) - pq\} - c \quad (6)$$

and c is a constant chosen so that $E(H) = 0$.

Note that to write such a hedge contract, all the factors x that affect the prosumer's production and consumption must be observable and contractible.

The Optimal Retail Contract - 2

The optimal retail contract takes a simple form:

$$R(q, p, x) = \underbrace{pq}_{\text{Correct price signals}} - \underbrace{H(p, x)}_{\text{Hedge contract}} \quad (7)$$

The first part ensures the customer faces the correct price signals at the margin and makes the efficient production/consumption decisions $q^*(p, x)$.

The second part ensures that the customer is **perfectly hedged** (i.e., faces no risk):

$$\begin{aligned} \forall p, x, \pi(q^*(p, x), p, x) &= V(q^*(p, x), p, x) - R(q^*(p, x), p, x) \\ &= V(q^*(p, x), x) - pq^*(p, x) - H(p, x) + c \\ &= c \end{aligned} \quad (8)$$

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Properties of the hedge contract $H(p, x)$

$V(q, x)$ and $-H(p, x)$ are **convex conjugates**.

- Since $V(q, x)$ is concave, $H(p, x)$ is convex.
- $V(q, x)$ is the gross consumer's/producer's surplus; the hedge contract $H(p, x)$ is the conventional net consumer's/ producer's surplus.
- The slope of the hedge contract with respect to p is $-q$; the slope of the value function with respect to q is p :

$$\frac{\partial H}{\partial p}(p, x) = -q^*(p, x) \text{ and } \frac{\partial V}{\partial q}(q^*(p, x), x) = p \quad (9)$$

- The convex conjugate of $-H(p)$ is $V(q)$.

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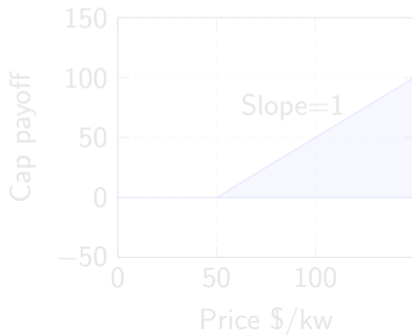
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Constructing the hedge contract - 1

At this point it looks like we need a separate, bespoke hedge contract (and retail contract) for every single retail customer. But it is possible to approximate the hedge contract arbitrarily closely using a set of standardised hedges (Caps and Floors).

The payout on conventional Caps and Floors depends on the strike price S and the volume V . Here are two examples:

Cap($p|S = \$50, V = 1$)



Floor($p|S = \$50, V = 0.5$)

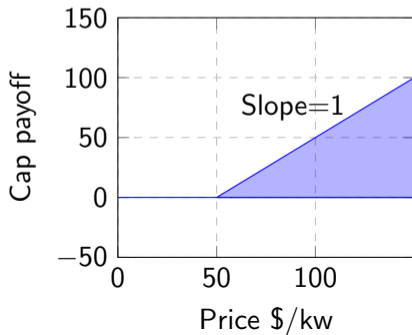


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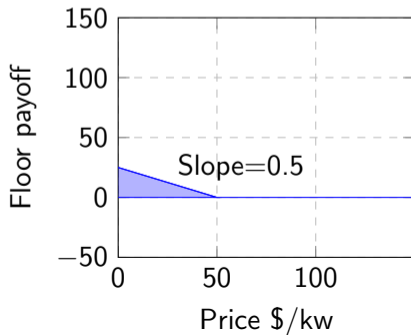
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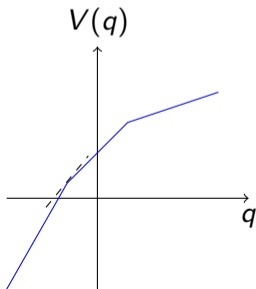
Constructing the hedge contract - 2

Let's focus on the special case in which there are no x factors.

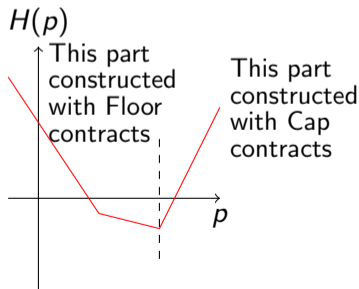
Theorem

For any piecewise-linear, upward sloping value function $V(q)$, the corresponding hedge contract $H(p)$ (the convex conjugate) can be expressed as the sum of a portfolio of Caps and Floors.

An arbitrary
piecewise-linear
value function...

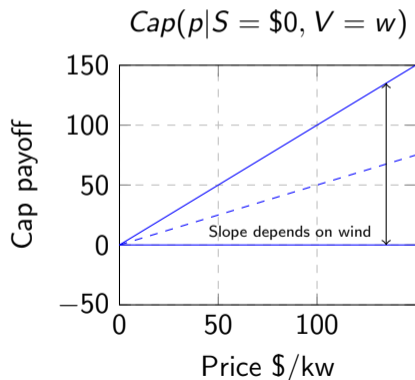


... has a hedge contract which is
a sum of Caps and Floors.



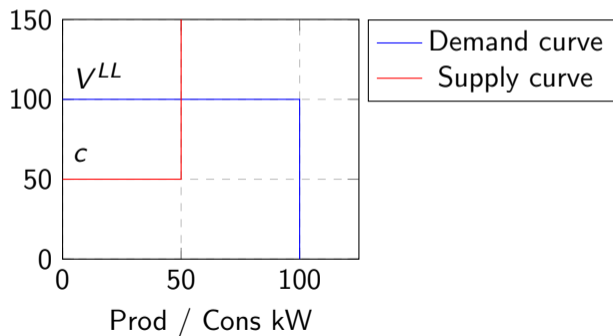
Constructing the hedge contract - 4

In the more general case the value function $V(q, x)$ and therefore the hedge contract $H(p, x)$ depends on x . We need a larger range of ('exotic') Caps and Floors, with a volume that varies with the factors x . For example, a 'wind-following' Cap:



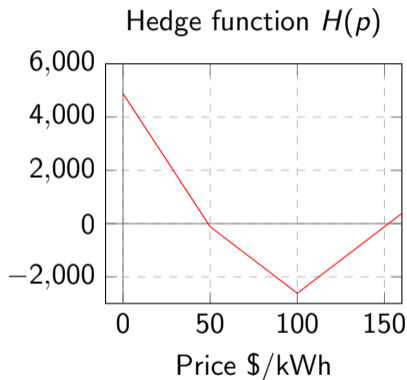
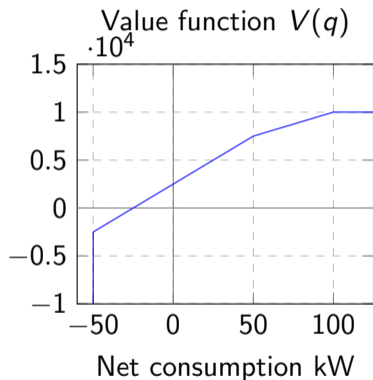
Example #1 - 1

Let's consider the simplest possible case of a prosumer which combines a simple load and a simple generator. The load has a value of V^{LL} \$/kWh for consumption up to exactly 100 kW. The generator has a variable cost of c \$/kWh and a capacity of 50 kW. Since these are assumed fixed there is no dependence on any other factors which we labelled x .



Example #1 - 2

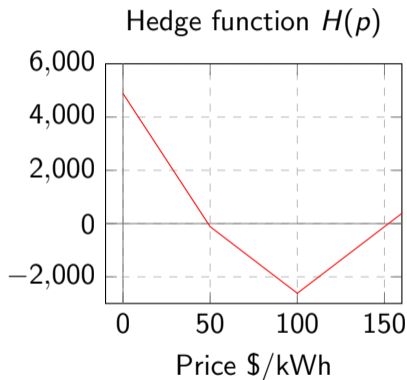
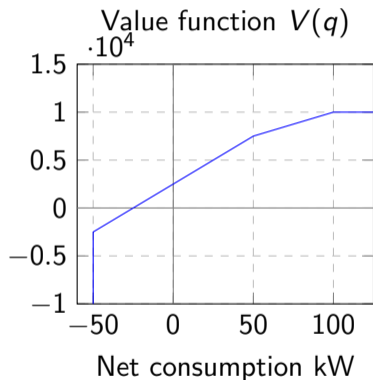
We can calculate the value function and the optimal hedge function in the case $V^{LL} = \$100$, $c = \$50$:



The hedge contract involves payments *from* the retail customer when prices are either very low or very high. When prices are in the middle of the range, the retail customer receives payments from the hedge contract.

Example #1 - 2

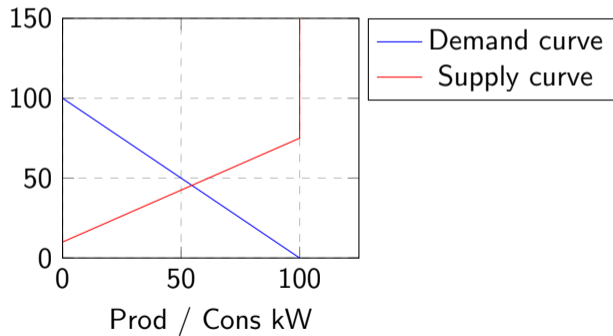
We can calculate the value function and the optimal hedge function in the case $V^{LL} = \$100$, $c = \$50$:



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Example #2 - 1

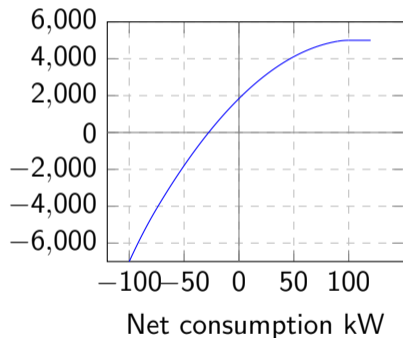
Let's consider a prosumer that has a load with a linear, downward-sloping demand for electricity of the form $d = 100 - p$, and a generator with a linear, upward-sloping supply curve, of the form $g = \frac{p-10}{1.2}$ up to a capacity of 100 kW.



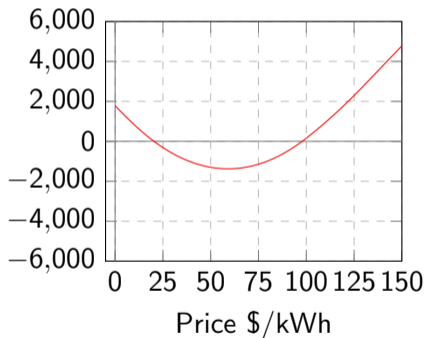
Example #2 - 2

Again, we can set out the value function $V(q)$ and the corresponding optimal hedge function $H(p)$. Again, $H(p)$ is a convex function.

Value function $V(q)$



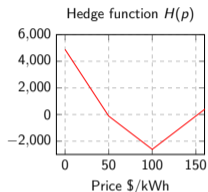
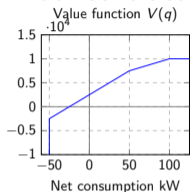
Hedge function $H(p)$



Again, the hedge component of the contract involves payments to the customer when the price is very small or very large.

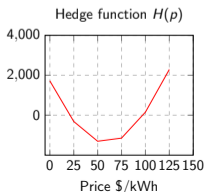
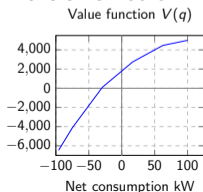
Constructing the hedge contract - 4

In the case of example #1, the hedge contract is obtained from a simple sum of a Cap and a Floor contract:



$$\text{Portfolio } \text{Floor}(p|\$100, 100) + \text{Cap}(p|\$50, 50)$$

In example #2, a portfolio of closely-spaced Caps and Floors can approximate arbitrarily closely the hedge contract (as a piece-wise linear function) which, in turn, can approximate the value function.



What about the investment decision?

We have seen that the optimal retail contract perfectly insulates the customer from risk. Does the customer retain the correct incentives to invest in local production or consumption assets?

The answer is yes: Since $E(H) = 0$, the expected pay-off of the customer is just equal to the expected consumer's surplus or producer's surplus. From equation 8:

$$\forall p, x, E(\pi) = c = E(V(q^*(p, x), x) - pq^*(p, x)) \quad (10)$$

Therefore, when considering whether to make an investment, the customer must change his/her hedge contract to reflect the new set of production/consumption assets, but his/her expected welfare changes by exactly the change in welfare to society – so the customer faces the correct incentives to invest in new assets.

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- In principle the same logic applies, but we need a range of Caps and Floors (both conventional and exotic) *at every pricing location*.
- In other work we have shown that the system operator can also insulate itself from risk (variation in the MS) by making available a range of Generalised FTRs.
- But, (even with GFTRs) the number of standardised hedge contracts required is very large and possibly impractical. The full implications of this is a question for on-going research.

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What can we learn from this analysis?

- 1 We should separate the price-signalling and risk-management issues. Debates over TOU, CPP, demand charges, seem to force a trade-off between price-signalling and risk-management issues. This analysis suggests that we can (at least under certain assumptions) achieve *both* efficient price signals *and* perfect hedging.
- 2 The retailer must understand the customer and his/her resources. The optimal hedge contract depends on the customer's value function, so the retailer must know the shape of the value function, including how the customer responds to the local price p and the other factors x . This requires information about customer production and consumption assets. How will that information be conveyed to the retailer on an on-going basis?

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- 4 **Retailers must have access to a range of suitable hedge contracts** including the more exotic contracts discussed here. The government could potentially play a coordination role in creating standardised contract forms (e.g., defining wind speed metrics).
- 5 **Maintaining the liquidity and effectiveness of the hedge market is important.** Governments may be able to improve liquidity in hedge markets by providing insurance against uninsurable events such as, for example, the exercise of market power, the timing of the exit of large generators, or government actions which may shift future prices.
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- That simple form involves exposure to wholesale spot prices at the margin, coupled with a hedge contract which perfectly insulates the customer from risk.
- This hedge contract is the convex conjugate of the value function and can be constructed from standardised hedge contracts (Caps and Floors - both conventional and exotic).
- Debates about TOU, CPP etc. reflect a conflict or trade-off; it is preferable to resolve that trade-off with tools to insulate retail customers from risk.
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