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Prepared for
Electric Power Research Institute
3412 Hillview Avenue
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EPRI Project Managers
F. P. Sioshansi
Retail Market Tools and Services
Customer Systems Group

C. Smyser
Power Markets and Resource Management
Power Delivery Group

THE ROLE OF FINANCIAL INSTRUMENTS IN A COMPETITIVE ELECTRICITY MARKET

Shmuel S. Oren
Department of Industrial Engineering and operations Research
University of California at Berkeley
Berkeley, CA 94720

Abstract

It is generally accepted that competitive electricity markets require an active spot market that will reflect changing supply and demand conditions. However, while spot markets are useful in achieving short term efficiency they must be accompanied by forward and derivative markets that will facilitate efficiency-motivated transactions, risk management (through hedging), speculation (which helps diversify risk and create liquidity), and capital formation for investment. The formation of liquid financial markets for electric power will have a profound impact on the planning and operations of the electricity system. On the operation side, employing financial instruments to emulate efficiency-motivated contracts will have important operational implications with respect to scheduled transactions. The boundary between physical deliveries and financial settlements will be blurred in such an environment. Thus, an operator who traditionally controlled generation facilities, spinning reserves, demand side resources and dispatchable IPP's will have to coordinate such physical resources in concert with the trading and financial settlements of "paper resources" such as forward contracts, put and call options and other types of exotic derivatives that could replace physical deliveries or mitigate the risk associated with fluctuating demand and supply. This paper focuses on the implementation of efficiency-motivated transactions taking place today between utilities and customers and between utilities and IPP's through special supply contracts by means of standard financial instruments. Such implementation will reduce transaction costs and improve customer choice. We will illustrate three examples of such transactions and the corresponding financial instruments: interruptible/curtailable service, dispatchable IPP contracts and priority service with early notification. We demonstrate the functionality of financial instruments in achieving production efficiency through customer and producer choice and discuss the pricing of such instruments.

1. Introduction

The debate regarding the ideal structure of a competitive electricity market and the implementation details of such a market is still raging. However, there is broad consensus, with regard to the need for an active spot market that will reflect changing supply and demand conditions. Spot markets for electricity are functioning to various extents in the UK, Norway, New Zealand, Australia and some Latin American Countries. In the US bulk power trades among utilities and real time pricing which attempt to emulate a true spot market is available to large industrial customers and municipalities. And of course, the Power Exchange plays a central role in all the California restructuring proposals and in the December, 1995 ruling by the CPUC.

While spot markets, which reflect short term marginal costs are useful in achieving short term efficiency they must be accompanied by forward and derivative markets which reflect cost expectation that incorporate market consensus with respect to investment opportunities and future efficiency improvements. These markets have several important roles:

Facilitating efficiency transactions
Risk management (hedging) and risk sharing
Speculation which helps diversify risk and facilitates liquidity
Capital formation for capacity expansion.

The formation of liquid financial markets for electric power will have a profound impact on the planning and operations of the electricity system. On the planning side many of the functions associated with capacity expansion will be combined with portfolio management activities where physical resources are viewed as part of the overall portfolio that also include long and short term financial contracts. Opportunities for diversification of risk, enabled by futures markets, will make capital asset pricing and portfolio management techniques relevant to the electric power industry planning functions. Furthermore, with a sufficiently liquid futures market, financing of projects through long term supply contracts (e.g. contracts between utilities and IPP's) can be replaced by simply selling of energy futures (or forwards) and raise capital for building the facility.

On the operation side, employing financial instruments to emulate efficiency-motivated transactions will have important operational implications with respect to scheduled transactions. The boundary between physical deliveries and financial settlements will be blurred in such an environment. Thus, an operator who traditionally controlled generation facilities, spinning

reserves, demand side resources and dispatchable IPP's will have to coordinate such physical resources in concert with the trading and financial settlements of "paper resources" such as forward contracts, put and call options and other types of exotic derivatives that could replace physical deliveries or mitigate the risk associated with fluctuating demand and supply.

The following section provides general background and brief survey of literature relevant to the use of financial instruments in the electricity industry. The subsequent three sections discuss special instruments aimed at implementing efficiency-motivated transactions such as curtailable service and dispatchable IPP generation.

Background

As in any commodity market, financial instruments and derivatives can be used to hedge or diversify risk. The simplest hedge is a forward contract which guarantees a fixed price for power regardless of the spot price. A forward contract specifies a quantity and time hence a supply contract may consist of a bundle of forward contracts for each time period. These may have the same price or vary in price depending on time of day, season etc. A forward contract may be implemented as a combination of physical delivery at the spot price and a purely financial Contract For Difference (CFD) which entitle or obligates its holder (the power purchaser) to receive or pay the difference between the spot price and the strike price. The combination has the effect of purchasing the power at the strike price. More elaborate CFD's may enable risk sharing by requiring financial settlement only for spot price fluctuations that exceed a specified range while within the range the both parties bear the risk of the spot price fluctuations. The range may vary with time to reflect increased uncertainty. In the UK, Contracts For Differences (CFD's) play an important role as risk management instruments allowing buyers and sellers to hedge against fluctuation in the pool prices. An excellent review and tutorial describing the different types of CFD's that evolved in the UK system is contained in a recent publication by ENRON and the RISK magazine (1). The CFD market, however, has limited participation (primarily buyers and sellers of power) and has not expanded to the point that would attract speculative trade which could produce the cash and liquidity that will support efficient investment. To meet that goal a futures market with standardized instruments that will attract broader participation is needed.

In typical commodity markets, contracts can either be settled by physical delivery or through financial settlements. For example a forward electricity contract may be settled by either delivering power or by paying its owner the difference between the spot price and the price specified in the forward contract. Similarly a call option can be settled by either providing or relinquishing a

claim to power when the option is exercised or by paying the difference between the spot market and the strike price. Typically, the volume of traded commodity contracts exceeds by far the volume of actual deliveries (by a factor of ten or more). This allows non participants in physical deliveries to "gamble" on the price of the commodity. Like in other commodities, such speculation would serves a useful purpose by increasing liquidity of the financial instrument and creating a deep cash market that can finance investments (at competitive market rates) in generation and transmission.

Efforts to facilitate electricity futures markets are underway in the US in Australia and in Europe. In the US, NYMEX has developed two proposed electricity futures for power delivered at Palo Verde and at Cob (on the California-Oregon border.) NYMEX has also voiced its opposition to the POOLCO model arguing that the "administered uniform prices" implied by that model will hinder the development of a futures market. The feasibility and possible impediments to the development of a Futures Market for electricity in the context of the UK and Norwegian deregulated electricity system is examined by Amundsen and Balbir (2). The paper provides a general description of a commodity futures market, the type of players involved and the general requirements for a successful market. Volatility in the underlying spot prices, delivery ability, product homogeneity and price transparency are some of the essential conditions. Competition in the underlying market and a need for hedging as well as perceived opportunity for speculative gains are also essential. The article compares some of the main features of future contracts in the UK and Norway which differ in duration, delivery schedule, and settlement. The two main impediment to an efficient futures market in the UK and Norway are, according to the paper, market power and storage. In the UK, the spot prices can be manipulated by the duopoly deterring potential players in the futures market. In Norway where most of the power is hydro, a dominant firm could employ its storage capability so as to reduce spot price fluctuations and that would inhibit the operation of a futures market. The later point is also argued on theoretical grounds by Newberry (3).

While commodity markets for electricity are still in their pre infancy stage there is little dispute regarding the importance of such markets for a truly competitive electric power industry. The purpose of this paper is, therefore, to take the next step and examine the type of instruments that may evolve in such markets in order to replace or expand some of the contractual arrangements between consumers utilities and IPP's in today's electric power industry. As in other commodity markets, various forms of financial derivatives evolve to meet specific risk management needs and demand for speculative investment opportunities. Such instruments are designed to reflect the specific risk characteristics associated with the commodity and the industry needs for risk

diversification. A financial instrument that provides a "perfect hedge" to a producer of a commodity, for instance, is desirable on several counts. It reduces information cost to the producer by eliminating the need for information that would otherwise be required to respond to market fluctuations and it enables efficient risk allocation by providing an instrument for trading risk. The design of perfect hedges, however, is specific to the commodity and we expect that the needs in the electric power market will motivate the development of special instruments.

The proliferation of financial derivatives over the last decade has been accompanied by an explosion in the academic and professional literature dealing with standard and exotic options. A thorough coverage of the subject is available in the texts by Cox and Rubinstein (4) and by Hull (5). A tutorial on option is also provided in the ENRON-RISK publication (1). There is only a handful of published work dealing specifically with electricity options. Cater (6) provides a basic introduction to the Black-Scholes formula and illustrates how it could be interpreted in the context of electric power contracts. Jones (7) discusses how utility managers can exploit futures markets to manage risks associated with planning decisions such as accelerating the maintenance operation of a power plant. Gedra (8) and Gedra and Varaiya (9) introduce the concepts of "callable forwards" and "putable forwards" and provides a thorough analysis of their efficiency properties and their potential use as substitutes to interruptible service and IPP supply contracts. The material in the following two sections is based on that work. The section on "double call" options is based on the authors unpublished working paper (10) describing a new instrument that can capture the effect of an early notification option in curtailable service contracts.

Callable Forwards for Interruptible/Curtailable Loads.

Curtailable service or priority service options are being offered by many utilities to industrial customers as a way to mitigate potential shortages and reduce the need for spinning reserves and capacity expansion. The methodological foundation for the design of priority service contracts and the relationship between such contracts and spot prices is described by Chao and Wilson (11). An alternative implementations as interruption insurance is described by Oren and Doucet (12).

In the presence of an active spot market for electricity, priority service can be implemented by setting a cap on the spot price. i.e.,. the customer is curtailed whenever the spot price exceeds a customer-selected level. Such a contract may be augmented by an insurance scheme which for a specified premium will pay the customer the cutoff spot price whenever curtailed. A properly designed contract will induce a customer whose curtailment cost is $V per MWh to select curtailable service with cutoff spot price $V and opt for full insurance of $V when curtailed. In

theory such a contract will make the customer indifferent between receiving service or being curtailed.

A contract which is equivalent to the one described above can be implemented by means of standard financial instruments. A customer with shortage cost of $V per MWh can purchase a forward contract for service and sell back a "European" call option (see (1)) excercisable at delivery time, with strike price $V. A call option with strike price $k entitles (but does not obligate) its holder to purchase power (at a specified time) at $k per MWh. Note that the underlying asset for the call option is the forward contract whose price may vary over time, however, at delivery time it must converge to the spot price. Thus, if at delivery time, the spot price is below $V the customer takes physical delivery for the forward contract. Otherwise, if the spot price exceeds $V then the call option (with strike price $V) is exercised and it offsets the forward contract in which case physical delivery is curtailed and the customer is paid the strike price of $V. The value of the call option which is collected by the customer when purchasing the contract is equivalent to the discount he/she would have obtained for a corresponding curtailabe service contract.

Figure 1 illustrates the contractual obligations, payment and choices available to the buyer and seller in the arrangement described above. The buyer who is assumed to know his/her own shortage cost is free to choose the strike price for the call option while the seller or holder of the call option decides whether to exercise it. Clearly, in a liquid market, a rational seller will exercise a call option with strike price k if and only if the spot price at delivery time p_0 exceeds k.

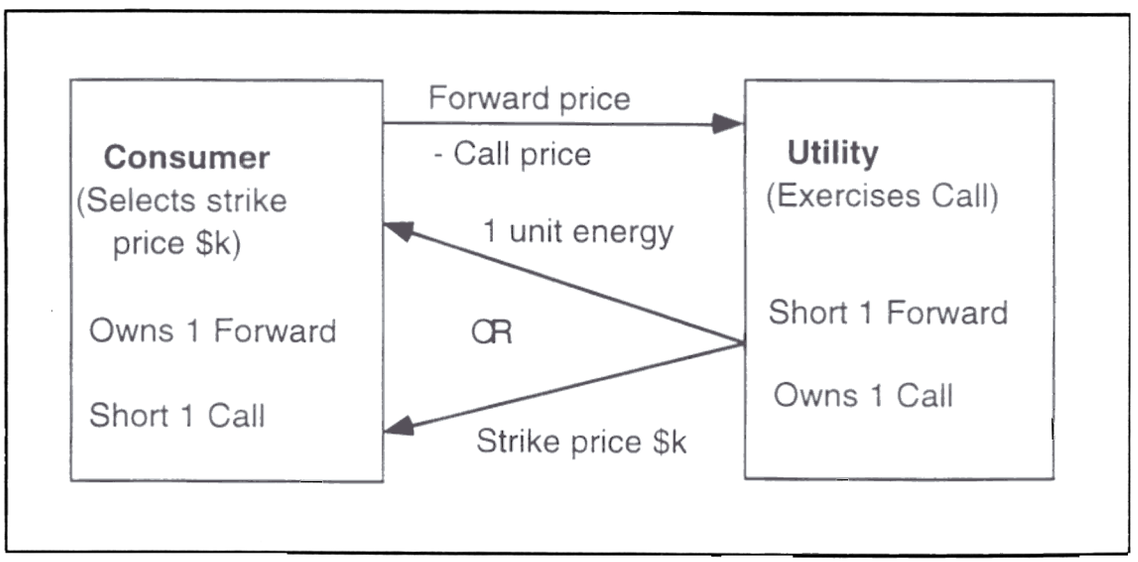

Figure 1.
Contractual Obligations, Payment and Choices Available to the Parties in a Callable Forward Arrangement.

Thus, the value of such an option at delivery time is: $C_0(k) = \max[0, p_0 - k]$ Consequently, at any time t prior to delivery, the market value of the call option $C_t(k|f)$ is the expected value of $C_0(k)$ with respect to the "risk neutral" probability distribution over he spot price at delivery time, conditional on the forward price at time t, i.e., $C_t(k|f) = E\{\max[0, f_0 - k]|f_t = f\}$. (see (4). Assuming a Log normal distribution for the spot price produces the same result as the Black Scholes formula where the volatility parameter representing the volatility of the underlying forward is related to the variance of the assumed distribution.

Gedra (8) proved that a hedging customer with no speculative motives will self-select to sell back to the supplier a call option (covered by his forward contract) with a strike price that equals his reservation price for the power. Optimal exercise of such call options by the supplier results in efficient rationing curtailing customers whenever the spot price exceeds their reservation price. Furthermore, the premium paid by the supplier for the call option equals the optimal discount corresponding to an equivalent interruptible service contract. Note that the above result makes the distinction between a hedger and a speculator. A hedger has a private value for the commodity which equals his curtailment cost while a speculator (who has no use for the commodity other than selling it) always values the commodity at its market value. In an efficient market the expected gain to a speculator buying a call is zero (aside from the competitive risk premium) hence a speculator would be indifferent with respect to the strike price while the hedger will maximize expected gains by selecting a strike price that exactly equal his/her shortage cost. In general, a customer purchasing forwards and selling back call options may have mixed motives speculative as well and hedging. It is useful in such a case to draw the distinction between the two and recognize that hedging transactions (which are limited to the quantity of potential use) should be valued based on the private value of physical use (i.e., the opportunity cost of curtailment).

Putable Forwards for Dispatchable IPP contracts.

Dispatchable IPP contracts typically consist of two price components. A fixed capacity payment and an energy price. In the simplest form of such a contract, the purchasing utility dispatches the unit only when the contracted energy price is below its own marginal cost (or the spot price when a spot market is functioning) and pays the contracted energy price for the purchased power. Dispatchable IPP contracts have been awarded by PG&E and by Consolidated Edison through competitive bidding. A discussion of such auctions and the implications of the scoring rules employed is given by Bushnell and Oren (13) and (14).

A dispatchable IPP contract can be emulated using standard financial instruments as follows. The IPP sells a forward contract for energy at a price corresponding to the energy price and a put option with a strike price equal to the same energy price. This enables the purchaser to sell back the power to the IPP when the spot price is below the contracted energy price, thus effectively canceling the original purchase. Figure 2, illustrates the contractual obligations, payments and choices available to the seller and buyer in the above arrangement. Clearly, a put option with strike price k will be exercised whenever the spot price is below that level. When that occurs, the IPP has the option to either turn off its power generation or continue to produce it and sell it at the prevailing spot price. In a competitive market, the IPP's energy price will equals its marginal production cost and the premium received for selling the put option will equal the competitive fixed capacity payment. An analogous long term contract can be constructed in which the buyer (e.g. utility) buys the power from the IPP at the prevailing spot price and buys a hedge from the IPP in the form of a "one sided contract for difference (CFD)" with a strike price that equals the IPP's energy price. The CFD entitles the buyer to all the cumulative excess of the spot price above the strike price. Thus if the IPP shuts off generation when the spot price falls below its energy price and pays back to the utility any amount it collects above that price, the net effect is that the buyer purchases power at the IPP's energy price if and only if it does not exceed the spot price.

As illustrated in Figure 2, the IPP whose energy cost is its own private information selects the strike price of the put option while the buyer who holds that option decides whether to exercise it. At delivery time, the put option value is, therefore, determined as $P_0(k) = \max[0, k - p_0]$

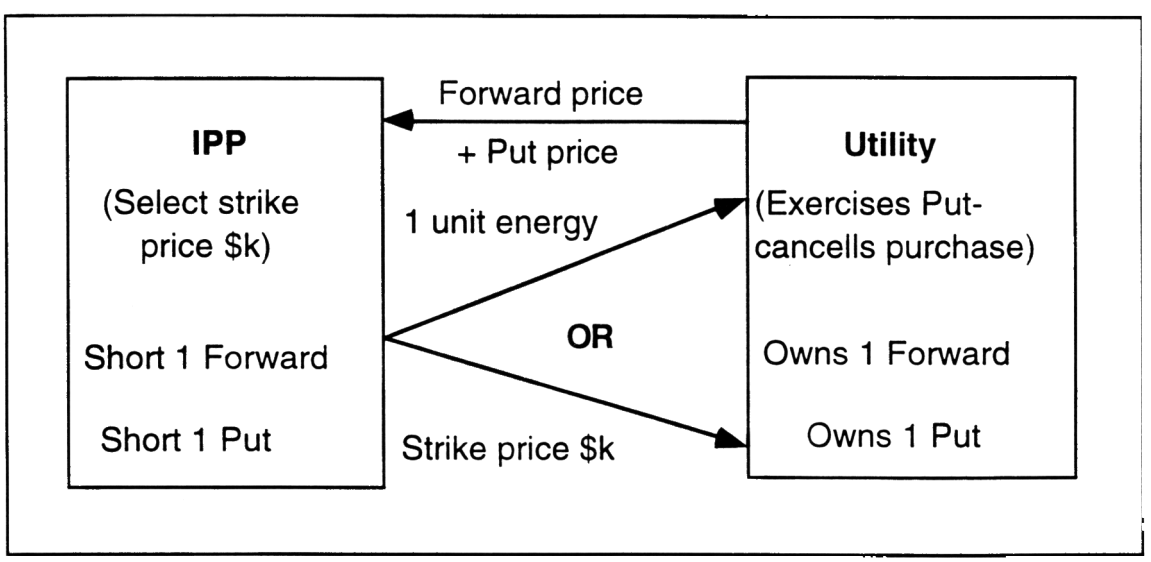

Figure 2.
Contractual Obligations, Payments and Choices Available to the Parties in a Putable Forward Arrangement.

Consequently, at any time t prior to delivery, the market value of the put option $P_t(k|f)$ is the expected value of $P_0(k)$ with respect to the "risk neutral" probability distribution over the spot price at delivery time, conditional on the forward value at time t, i.e., $P_t(k|f) = E\{\max[0, k - f_0]|f_t = f\}$. Assuming a Log normal distribution for the spot price produces the same result as the Black-Scholes formula where the volatility parameter representing the volatility of the underlying forward is related to the variance of the assumed distribution.

Gedra (8) has proved that an IPP with no speculative intention, who seeks to hedge against spot price uncertainty, will maximize expected gain by self-selecting to sell a put option on a forward contract with a strike price that equal his/her marginal cost of generation. Optimal exercise of such put options by the buyer will result in cancellation of the purchase whenever the IPP's marginal cost exceeds the spot price. This is equivalent to a dispatchable IPP contract paying a capacity price and an energy price that equals marginal cost. The market valuation of the put option in an efficient market will equal the capacity payment that would result from an efficient IPP auction. Again, for a speculator who values electricity at delivery time at its spot market price, the expected gain from holding a put option is zero. Hence a speculator would be indifferent to the strike price of the option.

Double Call Options for Priority Service with Early Notification .

Most interruptible service contracts offer alternative warning times. Tariff T-3 of Southern California Edison and Tariff E-20 of PG&E, for instance, offer higher discounts for shorter notification of an impending curtailment. A shorter warning requirement enables the utility to substitute interruptible load for spinning reserves and reduces its unit commitment cost. Consequently a shorter warning time entitles the customer to a lower rate. From the customers point of view, earlier notification of an impending curtailment may mitigate the shortage costs (for example by closing operation). A similar situation exists with respect to long term supply contracts. In countries that heavily depend on hydro, such as New Zealand, there have been initiatives to develop approaches for early long term notification (say several months) of projected shortages due to low hydro reserves. With proper price incentives such early notification could motivate an Aluminum smelter, for instance, to plan a seasonal shutdown.

A methodology for the design of priority service price schedules with an early notification option is described by Strauss and Oren (15). Service contracts with curtailment and early notification options can be alternatively implemented through financial instruments. Say a customer has a shortage loss $\$V_0$ per MWh if curtailed close to delivery time but a lower shortage cost of $\$V_T$

per MWh if a shut down is planned at an early date T prior to the physical delivery date. He/she could purchase a forward electricity supply contract and sell back an exotic call option which can be executed at delivery time at strike price V_0 or at time T before delivery at strike price V_T. The premium received by the customer for that call lowers his/her cost of doing business while the contract ensures that he/she will be curtailed only when the value of the electricity on the open market exceeds the customer's willingness to pay for it. Again, a perfect hedging instruments could reduce a customer's transaction costs by avoiding the need for continuous monitoring of spot prices, and enables customers to divest the unwanted risk.

Figure 3 below illustrates a contractual arrangement that can provide a perfect hedge for a customer who can mitigate shortage cost through early notification. In this arrangement, the customer purchases a forward contract and sells back a "double call" option that can be exercised either at an early date T prior to delivery or at delivery time at two different strike prices. The customer can select the two strike prices while the holder of the option decides if and when to exercise the call. An early exercise cancels the forward at time T prior to delivery and pays the early strike price while exercise at delivery time cancels the forward and pays the late strike price. If the call is not exercised the forward is settled through physical delivery.

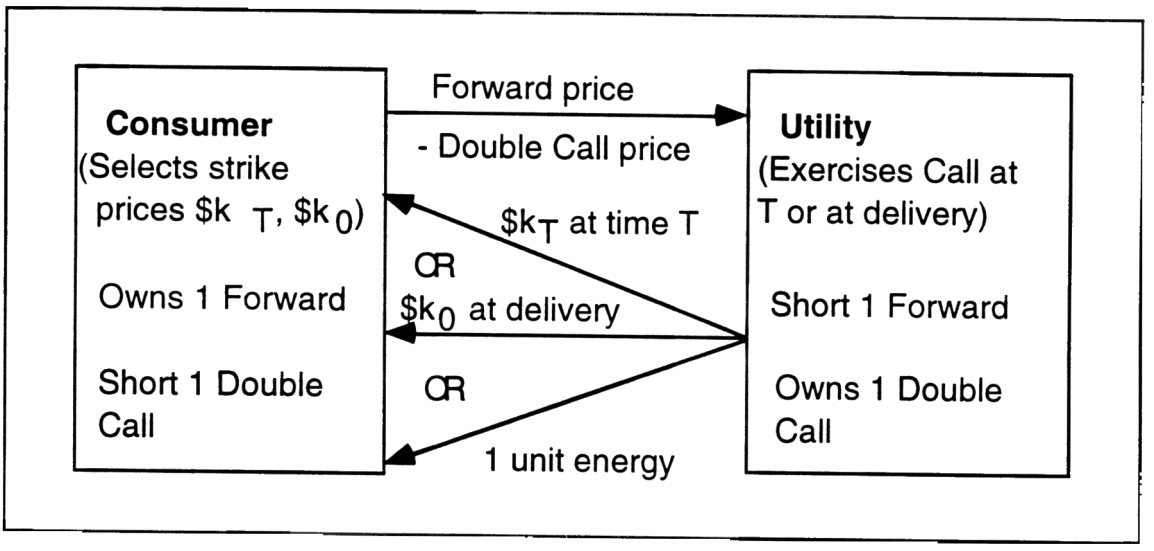

Figure 3.
Contractual Obligations, Payment and Available Choices in a Forward Contract Bundled With a Double Call Option.

The efficacy of a financial instrument in achieving allocative efficiency depends on its ability to induce customer and supplier choices that are consistent with the decisions that would have been taken by a benevolent central planner with perfect information. Figure 4 illustrates the decision

tree for a central planner with perfect information about customers' shortage costs and forward electricity contracts.

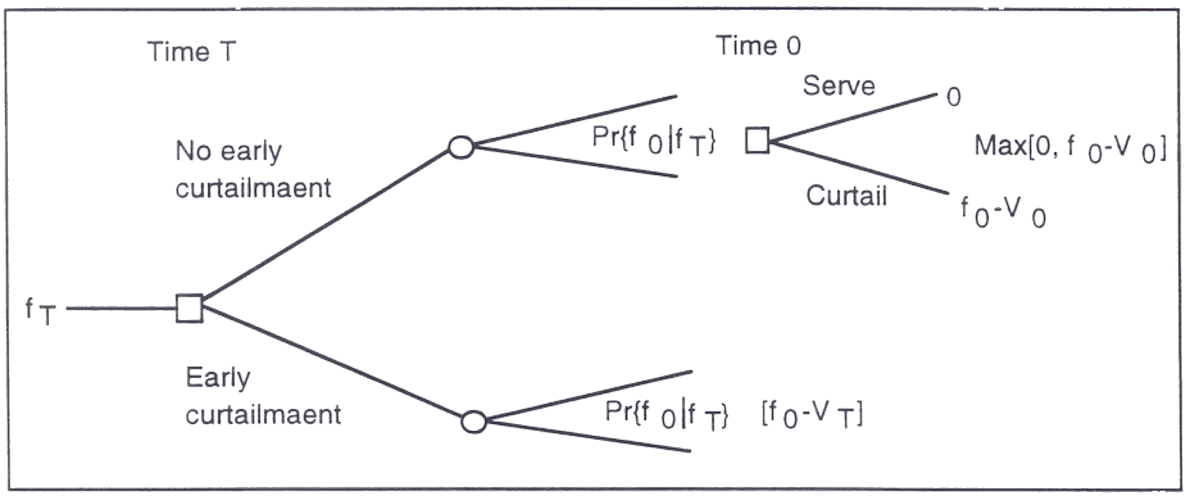

Figure 4.
Decision Tree at Early Date for Central Planner With Perfect Shortage Cost Information

At time T the planner knows the early and late shortage costs V_0 and V_T, the forward price f_T and the probability distribution $Pr\{f_0|f_T\}$ over the forward (same as spot) price at delivery. The immediate decision is whether to curtail at the early date or wait. Ignoring sunk costs, early curtailment yields the value of the forward at delivery less the early shortage cost. Foregoing early curtailment presents a second decision whether to curtail at delivery or deliver. Economic efficiency dictates curtailment at delivery if and only if the spot price exceeds the shortage cost. Hence, the net value (net of sunk costs or sure gains) of the second decision is the expected value of $\max[0, f_0-V_0]$ which is the value at time T prior to delivery of a simple call option with strike price V_0, given the forward price f_T, i.e., $C_T(V_0|f_T)$. Subsequently, the optimal decision at time T prior to delivery is to curtail if $f_T > \bar{k}$, where $\bar{k} - V_T = C_T(V_0|\bar{k}\}$. This result follows from an assumption that the forward price at any point in time equals the expected value of the spot price at delivery (this ignores interest) and the spot and forward prices reflect a competitive market equilibrium. Thus, the threshold forward price for socially efficient early curtailment is the sum of the immediate shortage cost plus the value of the forgone late call option. If the forward price at time T exceeds that threshold level it is socially optimal to curtail service at that time.

Let us consider now the exercise decision by the holder of a double call option with strike price k_T at time T and k_0 at time of delivery. The decision tree for such a decision is identical to that shown in Figure 4 with V_T and V_0 replaced by k_T and k_0. The corresponding optimal exercise decisions are therefore, to exercise at delivery if $f_0 > k_0$ and exercise at T prior to delivery if

$f_T > \bar{k}$ where $\bar{k} - k_T = C_T(k_0|\bar{k})$. This optimal exercise policy is illustrated in Figure 5 showing the early and late exercise regions as a function of the strike prices of the option and the forward prices at the early exercise date and at delivery.

Note that while the spot price threshold level for late exercise of a double call option equals the late strike price, the forward threshold value for early exercise depends on both strike prices and will always exceed the value of the early strike price (this accounts for the value of the remaining option if the option is not exercised early). Based on the optimal exercise policy it is possible to evaluate the double call option at any time t, as follows.

$$\hat{C}_t(k_T, k_0|f_t) = \begin{cases} C_t(k_0|f_t) & \text{for } t < T \\ \max[f_T - k_T, C_T(k_0|f_T)] & \text{for } t = T \\ E\{\max[f_T - k_T, C_T(k_0|f_T)|f_t\} & \text{for } t > T \end{cases}$$

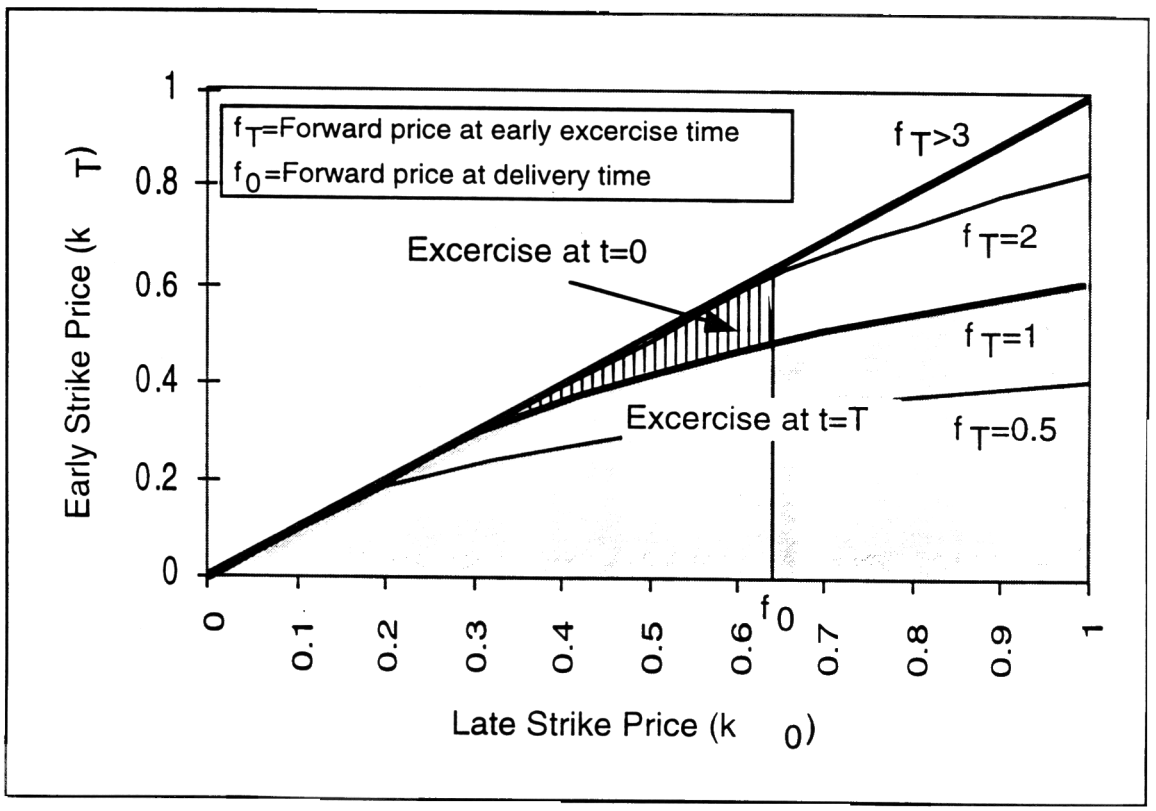

Figure 5
Optimal Exercise Policy for a Double Call Option

Figure 6 illustrates the value of a double call option at delivery time and at the early exercise time. The curved line in that figure represents the value of the late call option at the early exercise date

under the assumption of a Log normal distribution on the spot price at delivery (with a mean that equals the forward price at time T.)

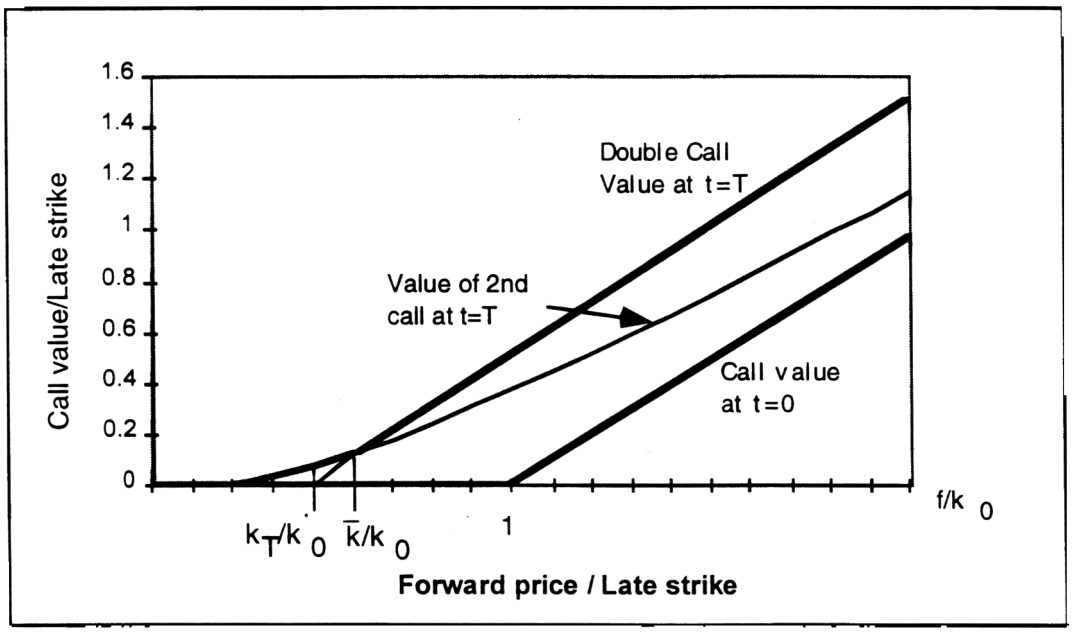

Figure 6

Value of Double Call Option at the Two Exercise Times

The valuation of the call option after the early exercise (assuming it is still alive) can be done in a straight forward manner using the Black-Scholes formula. However, the valuation of the double call option at times prior to the early exercise time is more involved and requires numerical integration or use of binomial trees. The details of the calculation are given in (10).

It is evident from the above analysis that the optimal exercise of a double call option with strike prices $k_T=V_T$ and $k_0=V_0$ produces the same outcome as socially efficient curtailment of a load with early and late shortage costs V_T and V_0. In a competitive environment, however, shortage costs are customers' private information. Thus, to achieve efficient curtailment through the exercise of double call options, it is necessary that customers will find it advantageous to select strike prices that equal their privately known shortage costs. Figure 7, illustrates the decision tree for a hedging customer with shortage costs V_T and V_0 having to select strike prices for a double call option. The customer takes into consideration the market valuation of such options and the optimal exercise strategy.

It is shown in (10) that indeed it is optimal (maximizes expected gain) for the customer to select strike prices that equal the corresponding shortage costs and therefore, optimal exercise of the call option will result in efficient curtailment. For a speculator, the decision tree in Figure 7 is the

same except for the fact that the speculator's shortage cost at delivery is the spot price at that time while the shortage cost at the early exercise date is the forward price at that time. With these changes the expected value of the lottery represented by the decision tree is zero (since that is how the efficient market prices the options.) regardless of the strike prices. Thus a speculator is indifferent to the strike price selection.

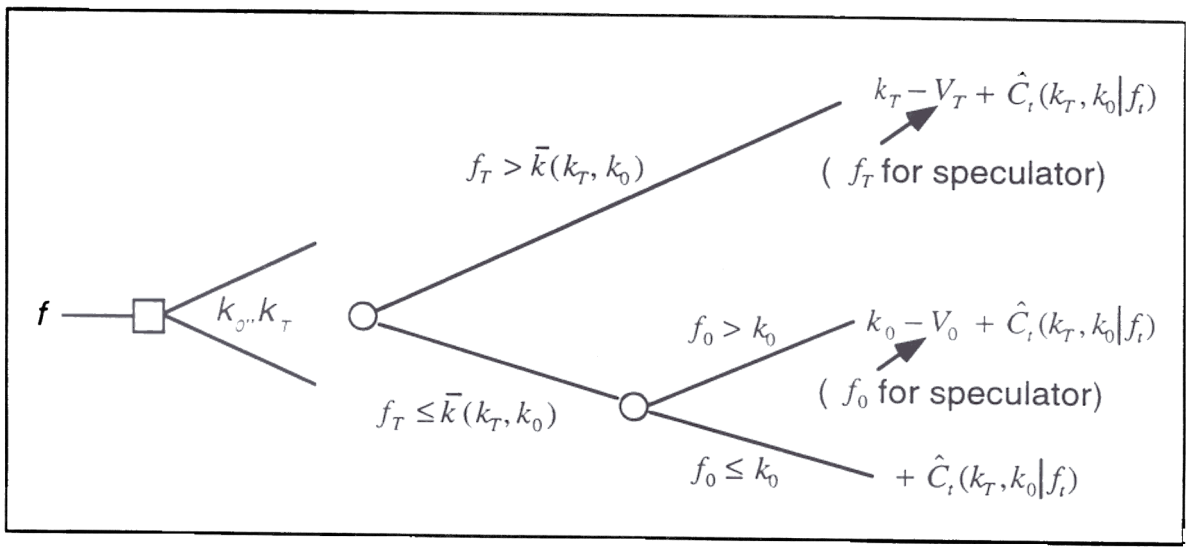

Figure 7

Customer Self-Selection of Strike Prices for Double Call Option

Conclusion

In a competitive electricity market, financial instruments and derivatives based on underlying commodity futures will play an important role as means for risk management speculative investments and capital formation. Such instruments can also emulate traditional contracts between customers, utilities and independent power producers aimed at improving the efficiency of resource utilization. Custom design of financial instruments can be specifically targeted at implementing such contracts in a decentralized environment with independent decisions by buyers and sellers. Such targeted instruments reduce transaction costs and provide perfect hedging tools for buyers and sellers of electricity. We have discussed three examples of derivatives each of which can be also implemented as a contract for difference. While one can conceive of many exotic forms of options that would meet specific needs for hedging and speculation we should also emphasize the importance of standardization. No financial instrument can be viable without sufficient liquidity and proliferation of customized instruments may result in "thin markets" with insufficient liquidity. It is not surprising, that only a small fraction of new futures and derivatives in stock and commodity markets develop sufficient liquidity to become viable.

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