California Independent System Operator Corporation

California ISO

Market alternatives to the congestion revenue rights auction

November 27, 2017

Prepared by Department of Market Monitoring

TABLE OF CONTENTS

1 Summary

The current Congestion Revenue Rights (CRR) auction design of the California Independent System Operator (CAISO) and other Regional Transmission Operators (RTOs) forces transmission ratepayers to sell complex financial contracts.[1] Without the simple protection of choice, ratepayers cannot avoid being made the counter party to unfavorable trades. CAISO transmission ratepayers have lost over $680 million in the CRR auction since 2009. The CRR auction continues to place ratepayers at risk of financial losses from unfavorable trades. Forcing ratepayers to sell financial contracts is unnecessary. Voluntary market trading and contracting can achieve the CRR auction's purpose.

The purpose of the CRR auction is to help energy market participants purchase contracts to hedge forward contract basis risk. A supplier may sell a forward contract at a different location than the location where the supplier sells power in the spot market. When this happens, the spot market settlement prices for the forward contract and the supplier's energy schedule will be different. The supplier will face an uncertain price difference not hedged by the forward contract. The uncertain price difference is locational basis risk.

The CRR auction is not necessary to allow suppliers to hedge basis risk. Energy market participants and financial traders can construct and trade financial contracts to hedge basis risks without the CRR auction — or the costs and risks the auction places on transmission ratepayers. This paper outlines some potential contracts that energy suppliers could use to hedge basis risk through voluntary markets.

Energy suppliers and buyers are natural trading partners that can hedge each other's spot market price and basis risks. But suppliers may want forward contracts where financial traders as well as energy buyers are potential trading partners. To facilitate trading with more potential partners, suppliers and financial traders can construct forward contracts so that supplier basis risks offset each other. By creating offsetting basis risks, suppliers can use basis risks associated with some forward contracts to hedge basis risks from other forward contracts.

To create offsetting basis risks, suppliers can simply settle forward contacts on an average of supplier location prices, i.e. at a *trade hub* price. Because the trade hub is an average price, basis risks between the trade hub and individual supplier locations will offset each other. Suppliers, with the help of financial traders, can hedge their basis risks by trading simple price swaps amongst themselves.

Centralized clearing could reduce transaction costs for trading price swaps. This paper also outlines a framework for a centralized swap market pool based on voluntary bids. The entity administering the central market pool does not need to be the ISO. Market participants can contract with each other, or with a separate entity, to create swap market pools.

A swap market, whether decentralized or centralized, would clear and determine prices for swaps based on voluntary trades. Unlike CRRs, the swaps traded would be consistent and well-defined products. In the CRR auction, involuntary trades and inconsistently defined products create opportunities to rent seek and extract payments from transmission ratepayers. A voluntary swap market would remove the opportunities to extract payments from ratepayers that exist in the current CRR auction.

[1] A detailed discussion of CRRS as purely financial contracts backed by transmission ratepayers is provided in a separate paper. See *DMM White Paper - Problems with the congestion revenue right auction,* Department of Market Monitoring, November 27, 2017. http://www.caiso.com/Documents/DMMWhitePaper-Problems_Performance_Design_CongestionRevenueRightsAuction-Nov27_2017.pdf

The contracts discussed in this paper may not be the only potential contracts that can hedge basis risks. Energy market participants and financial traders are free to construct whatever products or contracts they want. In a competitive market, we expect market participants and financial traders would create products and contract structures that best meet their needs.

2 Why CRR auctions should be reconsidered

Transmission ratepayers have lost over $680 million in California ISO CRR auctions since the auctions started in 2009. Overall transmission ratepayers received just $.52 in auction revenues per dollar paid out to CRRS purchased in the auction.[2] DMM has previously detailed problems with the CRR auction design which we briefly summarize here.[3]

The largest problem with the auction design is that not all trades are voluntary. The ISO offers financial contracts backed by transmission ratepayers in the auction. The ISO offers these contracts at zero offer prices and without regard to the costs the contracts impose on transmission ratepayers. Transmission ratepayers cannot choose which contracts to enter and which to walk away from.

The auction design relies on competition among auction participants to protect ratepayers from receiving systematically unprofitable contracts. Because ratepayers cannot avoid bad trade terms, an auction participant can extract economic rents from ratepayers. With sufficient competition for these rents, auction participants could bid up CRR prices and dissipate the rents through higher auction payments.[4]

But competition has not protected ratepayers in CRR auctions. In practice CRRs are inconsistently defined between the auction and the spot market settlement. That is, CRRs are not well-defined property rights.[5] Poorly defined property rights and significant transaction costs in a highly complex CRR auction limit the ability of competition to dissipate rents through prices. The CRR auction places ratepayers at risk of financial losses from unfavorable trades and rent extraction.

As explained below, CRRs are not rights to transmission service and are not needed for transmission access. The CAISO's spot market provides transmission access to all participants. The spot market allocates scarce transmission among participants based on the highest value use of the transmission system based on market bids.

Fortunately the problem faced in forward contracting is not procuring forward transmission service. The problem is hedging forward contract basis risk. Suppliers can use CRRs procured in the auction to hedge forward contract basis risk. But simpler alternatives can allow basis risk hedging that do not require imposing costs and risk on ratepayers. Forcing ratepayers to back financial contracts in the CRR auction is unnecessary

---

[2] DMM calculated these losses from CRR and LMP data. DMM regularly reports on ratepayer auction losses. For example see: Department of Market Monitoring, *Q2 2017 Report on Market Issues and Performance,* September 25, 2017: http://www.caiso.com/Documents/2017SecondQuarterReport-MarketIssuesandPerformance-September2017.pdf.

[3] See 2017 DMM paper on *Problems with the congestion revenue right auction* (footnote 1).

[4] Whether this competition would restore an efficient allocation of contracts, given costs to ratepayers are ignored, is unclear.

[5] *Problems with the congestion revenue right auction, pp. 18-19.*

3 Basis risk drives the need to hedge locational price differences

Auctioned CRRs are not rights to transmission service. The ISO's day-ahead market is a centrally cleared market. Market participants do not trade directly with each other. Suppliers sell power to the central market at their local price. Load serving entities buy power from the central market at their local price. Suppliers and load serving entities do not ship power between locations. A CRR is not needed as a right to ship power or for transmission access.

A CRR can hedge locational price differences. The demand for a hedge against locational price differences comes primarily from forward/futures contracting on energy prices.[6] Energy suppliers, load serving entities, and others trade forward contracts outside the ISO markets. A supplier may sell a forward contract at a location different than the supplier's spot market location. When this happens, the day-ahead settlement prices for the forward contract and the supplier's energy schedule will be different. The supplier will face an uncertain day-ahead price difference not hedged by the forward contract. This uncertain price difference is locational basis risk.

If a supplier forward contracts with an energy buyer that owns rights to congestion rent, then both the supplier and buyer will be hedged if the contract settles on the supplier's locational price. But a supplier might not want to trade directly with an energy buyer. The supplier may want to trade at a location different than its price location.

Why would a supplier expose themselves to basis risk by selling a forward contract at a different location? Even though the price at the supplier's location is very important to the supplier, it is not particularly important to most other people. The supplier may not find many partners to trade forward contracts with at their location. With fewer trading partners, the supplier would find it more difficult to enter, or exit, forward contracts that settle on their locational energy price. Of course this is a problem for all suppliers, not just any single supplier. Suppliers and market participants solve this problem by trading forward contracts at trading hubs.

A trading hub is an average of supplier locational prices. A trading hub gives market participants a reference price to settle forward contracts against. With lots of people interested in buying and selling at a trade hub, trading becomes easier. But by forward contracting at this reference price suppliers expose themselves to basis risk. The reference price could be any single locational price or grouping of locational prices. However, the choice of reference price has implications for hedging basis risk.

An average price across locations has a useful property for hedging basis risk. By definition, the sum of the differences between an average and each observation within the average is zero. That is, the sum of differences between the trade hub price and each locational price within the trade hub is zero.[7] The basis risks between the trade hub price and each supplier locational price offset each other. As explained below, the offsetting basis risks mean suppliers can hedge their basis risk from forward contracts at a trade hub by trading amongst themselves.

[6] We use the term *forward* to refer to all contracts settling on spot prices made before the spot market.

[7] For weighted average prices the weighted differences between the trade hub price and locational prices sums to zero.

4 Managing basis risk through voluntary decentralized market trades

To hedge locational basis risk a supplier could buy a contract called a *price swap*. A locational price swap pays the spot market price difference between two locations. If every supplier whose location is part of a trade hub bought price swaps from their location to the trade hub, in the same proportions as their location's weight in the trade hub, the sum of the spot market settlements of their swaps would be zero dollars. This summation to zero means that the basis risks of all suppliers hedge each other in aggregate. Energy suppliers are natural trading partners for price swaps amongst themselves.

Though no particular supplier may want the exact opposite swap trade as another supplier, overall the forward swaps from all supplier locations to a trade hub offset each other. That is, if a person traded forward swaps with each supplier whose resource contributes to a trading hub price, this person could use spot market receipts from some swaps to pay out the other swaps. In effect, this person would connect energy suppliers allowing them to trade with each other. In a decentralized financial market, financial traders would be the people connecting willing buyers and sellers of price swaps.[8]

Suppliers could buy swaps to hedge their forward contract basis risk. Financial traders could create portfolios of swaps that hedge their own spot market risk and earn returns. Table 1 and Table 2 show a simple example of how price swap trading at a trade hub can allow market participants to hedge their risks. The example trade hub has a weighted average price similar to the California ISO trade hubs.

Table 1 shows location names, the weight of each location's price in forming the trade hub price, location prices, the trade hub price, and the locational price less the trade hub price. The uncertain spot price difference between a location and the trade hub is the basis risk for a supplier that forward contracts at the trade hub. To hedge the basis risk a supplier can buy a price swap that pays them the trade hub price minus their locational price.

Table 2 shows a financial trader's swap portfolio. The financial trader holds swaps at each location in the same proportion as the location's weight within the trade hub. In this example, the trader sold each swap at a 10 percent premium in the forward market. The 10 percent premium is arbitrary and meant to show how the trader could earn profits.

Because the trader's portfolio is a complete weighted set of the trade hub, the trader's total spot market payments are zero. The trader is completely hedged against spot market risk and can earn a profit without even having an opinion on any future price spreads.[9] While a completely hedged portfolio would be ideal, in practice a financial trader would likely have some exposure to the spot market. In fact, a financial trader's job is managing their portfolio, risks, and expected profits.

The example has two main points. First, market participants can manage basis risk through voluntary trading without forcing transmission ratepayers to back financial contacts. Second, a portfolio of swaps can significantly reduce risks relative to any one price swap. Financial traders that better manage their portfolio risks can offer more competitive premiums to people seeking to hedge risks. A market where participants are free to choose which financial contracts to trade can create products and contract structures to manage spot market risks, including basis risks.

---

[8] As opposed to the alternative of a centralized market pool like the one described in the next section.

[9] In other words, the trader does not need to anticipate the price spread between each node and the trading hub in order to earn a profit. The trader just needs the net of all of his forward payments to be positive.

Table 1. Locational and trade hub prices

Location	Hub Weight	Energy Prices Node	Node-TH
Node A	15%	$20.00	-$5.10
Node B	10%	$30.00	$4.90
Node C	25%	$24.00	-$1.10
Node D	20%	$25.00	-$0.10
Node E	30%	$27.00	$1.90
Trade Hub	**100%**	**$25.10**	**$0.00**

Table 2. Financial trader's swap portfolio in the spot market

Swap	Swap MW	Payment per MW		Total Payments		Swap Profit
		Forward	Spot	Forward	Spot	
Node A-Trade Hub	15	$5.61	-$5.10	$84.15	-$76.50	$7.65
Node B-Trade Hub	10	-$4.41	$4.90	-$44.10	$49.00	$4.90
Node C-Trade Hub	25	$1.21	-$1.10	$30.25	-$27.50	$2.75
Node D-Trade Hub	20	$0.11	-$0.10	$2.20	-$2.00	$0.20
Node E-Trade Hub	30	-$1.71	$1.90	-$51.30	$57.00	$5.70
Portfolio	**100**			**$21.20**	**$0.00**	**$21.20**

5 Managing basis risk through a voluntary centralized market pool

Market participants can hedge basis risks without forcing ratepayers to back financial contracts through the CRR auction. The basis risks suppliers seek to hedge are created by forward contracting for energy — not a need to procure forward transmission rights. These basis risks can be hedged with simple swap contracts and without a product defined by estimates of complex transmission models.

Unlike CRRs, a simple price swap is a well-defined property right.[10] A market with well-defined property rights and trading confined to willing parties is much less susceptible to gaming and rent extraction than the current CRR auction. A market with well-defined property rights and voluntary trades is also more likely to create competitive market prices based on people's willingness to trade than the CRR auction.

As shown above, financial traders would need to create swap portfolios with similar proportions to the trade hub weights. However, multiple transactions may be needed for financial traders to create

[10] Because what you buy is what you get. A CRR is not a consistently defined product as described starting on p.11 and on pp. 17-19 of Department of Market Monitoring, *Shortcomings in the congestion revenue right auction,* November 26, 2016: http://www.caiso.com/Documents/DMM-WhitePaper-Shortcomings-CongestionRevenueRightAuctionDesign.pdf.

balanced swap portfolios. Multiple transactions could increase the costs of trading. A centralized clearing mechanism could reduce the number and costs of needed transactions.

The following sections outline a framework for a centralized market pool to clear basis swaps around a trade hub. The ISO could undertake the central clearing function. But the ISO has no natural advantage in centrally clearing swaps.[11] To the contrary, other entities may have advantages over the ISO in areas like credit management and contracting flexibility.

Furthermore, as explained below, the quantity of completed trades could be increased by thoughtfully incorporating the expected demand for swaps into the determination of each trading hub's weights. Therefore, entities other than the ISO may be better equipped to optimally coordinate the swap clearing process with the design of the trading hubs. While we outline a general framework without every detail, we would expect a competitive financial market to create products and contracting structures that meet the needs of participants in the energy market while minimizing transaction costs.

5.1 Central swap clearing pool without spot market price risk

We start the framework assuming the central market pool cannot take any spot market risk— i.e. that the net spot market payments are zero. To ensure no net spot market payments, the central pool must clear swaps at each location in the same proportion as the trade hub weights.

The objective of the market pool is to maximize the total value of cleared swaps, as shown in Equation 1. "S" is the quantity of swaps cleared. "P" is the bid price. "i" indexes individual swap bids while "j" indexes swap locations within the trade hub. A swap at location "j" will be paid the trade hub price minus the price at location "j" in the spot market. "w" is the weight of a location within the trade hub. For each location the total swaps cleared at the location divided by the total cleared swaps in the market must equal the location's weight.

Equation 1. Swap market clearing with no spot risk

$$\max_{S_i} \sum_i P_i S_{i,j} \quad s.t. \quad \frac{\sum_{i \in j} S_{i,j}}{\sum_i S_{i,j}} = w_j \;\forall\, j$$

Equation 2. Swap market clearing with no spot risk

$$\max_{S_i} \sum_i P_i S_{i,j} \quad s.t. \quad \sum_{i \in j} S_{i,j} - w_j \sum_i S_{i,j} = 0 \;\forall\, j$$

Equation 2 reformulates the trade constraints to be easier to solve. The optimization clears swaps such that the total forward market payments sum to zero and the spot market payments sum to zero (as shown below in sections A.1 and A.5). The central pool has no risk and neither receives profits nor

[11] The ISO runs the CRR auction because it creates the transmission models that define the CRRs and can charge the accounts necessary to secure ratepayer backing.

incurs losses. The pool is revenue neutral. The pool administrator could be paid a transaction fee for its service similar to other market exchanges.

The central swap pool outlined here has several advantages over the current CRR auction:

- The market would price and clear swaps based on voluntary bids and trades;
- The swaps would be consistently defined property rights between forward and spot markets;
- The pool clearing is based on simple average concepts; and
- The market pool removes rent seeking opportunities that exist in the CRR auction.

Constraining the ratio of swaps cleared at each location to the location's trade hub weight can limit trading if demand for basis risk hedges are not in the same ratio as the location weights. We can think of at least three ways to reduce the limitations from the ratio constraints.

First, the pool administrator could set the trade hub weights as close as possible to the expected demand for basis swaps. Therefore, careful consideration of the expected demand for swaps at each location within a trading hub when designing the weights of each trading hub would be likely to increase the quantity of completed trades.

Second, financial traders can participate in the market pool. Financial traders can clear swaps to keep the ratios of swaps trades balanced with the locational weights. Financial traders could submit bids stating the price at which they would be willing to buy or sell a swap. The trader's swap will clear if clearing the swap will increase total market value. This would, in turn, increase the amount of other swaps traded in the market. Financial traders could even submit negative quantity swap bids at a location and trade swaps "directly" with a participant hedging basis risk at the same location. This kind of direct trade would occur if the entity's bid price to buy the swap was greater than or equal to the price at which the trader offered to sell the swap.

A third way is for the pool administrator to relax the ratio constraints. The ratio constraints can be "relaxed" if the pool administrator clears its own swaps at various locations. These relaxation swaps would only make sense if the pool participants believe that sharing the risks from the swap relaxation is more valuable to them than relying on financial traders in the market. We do not discuss the merits of this type of risk sharing versus relying only on bid in trades. Below we only discuss how the market pool optimization could be altered to include relaxation swaps.

5.2 Allowing the central swap clearing pool to take spot market price risk

If the pool participants decide that they do not want to rely solely on suppliers and financial traders to submit sufficient bids at each location within the trading hub to clear the market, the central pool could "relax" these locational ratio constraints. The entity administering the central pool could relax the ratio constraints by clearing its own swaps in the market pool.

Clearing relaxation swaps works because the ratio constraints are really just constraining the quantity of swaps supplied by pool participants to equal the quantity of swaps demanded by pool participants. By clearing relaxation swaps the pool administrator allows the quantity supplied by pool participants not to equal the quantity demanded by pool participants. The pool would be trading with participants and the quantities supplied and demanded would balance only after considering the trades for which the pool is the counterparty. It is likely that the pool participants would like the swap relaxation trades to be with the pool at large and not with the pool administrator specifically.

The pool administrator could price the relaxation swaps to clear only when the money collected by the pool from these swaps will likely cover the payments from the pool—given a level of risk determined by the pool participants. For example, if a swap is expected to require its holder to pay $3 or less in the spot market 90% of the time, then if the pool receives $3 in the forward market for its relaxation swap, the pool can expect to completely cover the spot payments 90% of the time. Rather than financial traders pricing and managing these risks, the central pool administrator would. Clearly there could also be a mix of relaxations from the central pool administrator and bids from financial traders.

Equation 3 shows the central swap market clearing with relaxation swaps (R) added. The market clearing treats the relaxation swaps as if they were normal swap bids submitted by pool participants.

Equation 3. Swap market clearing with swap relaxations

$$\max_{S_i,R_i} \sum_i \left(P_i S_{i,j} + P_i R_{i,j}\right) \quad s.t. \sum_{i \in j} \left(S_{i,j} + R_{i,j}\right) - w_j \sum_i \left(S_{i,j} + R_{i,j}\right) = 0 \quad \forall\, j$$

Of course some percentage of the time the central pool will not be able to cover the costs of the swap relaxation from the money received. Someone will have to pay the swap relaxation costs. Conversely, some percentage of the time the money collected to cover the relaxation will be greater than the actual cost. Sometimes there would be a deficit and sometimes a surplus.

It seems reasonable to distribute the swap relaxation deficit or surplus to the swap market pool participants. With these distributions the swap market participants would share the pool risks and profits from the swap relaxations. The risks would be shared among those seeking insurance (i.e. those seeking to hedge risk), and those who voluntarily participate in the market based on their willingness to transact. This risk sharing also has the advantage of not placing the risks on unwilling parties who did not bid into the market or agree to take any risk.

Further, if the entity administering the swap pool faces competition, the entity would have an incentive to manage the pool's relaxation swap risks and profits in a manner that best serves the pool participants. If the pool administrator manages the risks poorly, the market participants can leave for a better managed pool. The pool administrator would face at least competitive pressure to provide good customer service and reasonable transaction fees. A private pool administrator would also have an incentive to act in ways that maximize the amount of trading in the swap market. The rules governing how the pool does or does not share risk, and how the pool administrator should operate generally, can be decided by the pool participants and the administrator as they develop contract terms amongst themselves.

6 Markets can manage basis risks without forcing contracts onto transmission ratepayers

Energy market participants and financial traders are free to develop and trade contracts to manage market risks, including basis risks. They can even contract to create swap clearing pools to lower transaction costs and facilitate basis swap trading. Forcing transmission ratepayers to back financial contracts in the CRR auction is unnecessary.

This paper outlined potential market frameworks for hedging basis risk based on voluntary trading and contracting. The market frameworks are relatively simple. The market frameworks would allow entities to trade consistently defined products and property rights to hedge risk between supplier location prices and trade hub prices that have more potential forward contract trading partners. Unlike the CRR auction, voluntary markets would not expose transmission ratepayers to financial losses from involuntary trades.

This paper outlines some potential forward products and contracting that can manage basis risk. Other products or contracting structures could emerge. We expect that in a voluntary market entities would create products and contract structures that best meet their needs.

Appendix

A.1 Sum of residuals from an average equals zero

It is well-known that the sum of the differences between an average and each observation is zero. Here we show the well-known proof where y_i are the observations and $\bar{Y}$ is the simple average.

$$\sum_i (y_i - \bar{Y}) \; = \; \sum_i y_i - \sum_i \bar{Y} \; = \; \sum_i y_i - n\bar{Y} \; = \; \sum_i y_i - n\frac{\sum_i y_i}{n} \; = \; \sum_i y_i - \sum_i y_i \; = \; 0$$

The sum of weighted errors between the weighted average and each observation is also zero. This can be shown similarly to the simple average. $Y_w = \sum_i w_i y_i$ is the weighted average where $\sum_i w_i = 1$.

$$\sum_i w_i(y_i - Y_w) \; = \; \sum_i w_i y_i - \sum_i w_i Y_w \; = \; \sum_i w_i y_i - Y_w \; = \; \sum_i w_i y_i - \sum_i w_i y_i \; = \; 0$$

Multiplying the weight by a constant would still result in a zero summation. Therefore the sum of spot locational price to trade hub price swap payments will equal zero if sold in the same ratio as the locational weights in the trade hub.

A.2 Central swap market pool reformulated trade balance constraints

To guarantee that the net spot market swap payments in a central pool equal zero, the ratio of the swaps cleared at each location to the total swaps cleared in the market must equal the location's weight in the trade hub. Applying these constraints in this formulation would be cumbersome. Reformulating the constraints will make them easier to use. Starting with the ratio constraints:

$$\frac{\sum_{i \in j} S_{i,j}}{\sum_i S_{i,j}} = w_j \;\; \forall \;\; j$$

Multiply both sides by $\sum_i S_{i,j}$:

$$\sum_{i \in j} S_{i,j} = w_j \sum_i S_{i,j} \, \forall \;\; j$$

Subtract $w_j \sum_i S_{i,j}$ from both sides:

$$\sum_{i \in j} S_{i,j} - w_j \sum_i S_{i,j} = 0 \;\; \forall \;\; j \; (or \; j - 1 \; because \; one \; constraint \; can \; be \; dropped)$$

Because each location j is in each constraint, one constraint is redundant and can be dropped. The reformulated constraints also make it clear that the swap market is clearing offsetting trades. Quantity supplied equals quantity demanded.

A.3 Central swap market pool formulation

A swap (S) at location j will be paid the trade hub price minus the price at location j. The trade hub price is the weighted average of locational prices. The swap market pool maximizes total bid value given that total swap trades balance.

One swap location (r) is designated the reference location to construct the trade balance constraints. The balance constraints are equivalent to quantity supplied equals quantity demanded, and equivalent to ratio of swaps traded at each location equals the location's weight in the trade hub.

Cleared swap quantities are constrained by the bid in quantities (S^{min} and S^{max}). The formulation also allows for no forced or self-scheduled swap trades.

$\underline{Swap\ market\ clearing\ optimization}$:

$$\max_{S_i} \sum_i P_i S_{i,j}$$

$$s.t.\ \sum_{i \in j} S_{i,j} - w_j \sum_i S_{i,j} = 0\ \ \forall\ j\ \ (or\ j-1)$$

$$S_{i,j}^{min} \leq S_{i,j} \leq S_{i,j}^{max}$$

$$S_{i,j}^{min} \leq 0$$

$$S_{i,j}^{max} \geq 0$$

$\underline{Term\ definitions}$:

S: $Cleared\ swap\ bids$

P: $Bid\ price\ for\ swaps$

w: $Location\ weight\ in\ trade\ hub$

i: $Indexes\ swap\ bids$

j: $Indexes\ locations\ within\ the\ trade\ hub$

r: $Reference\ location$

S^{min}: $Minimum\ bid\ quanity\ for\ swap\ bid$

S^{max}: $Maximum\ bid\ quanity\ for\ swap\ bid$

$$Price_{TH}^{spot} = \sum_j w_j Price_j^{spot} \qquad SwapPayment_{i,j}^{spot} = S_{i,j}\left(Price_{TH}^{spot} - Price_j^{spot}\right)$$

A.4 Central swap market pool prices

The swap clearing prices are derived from the optimization. The price at location L is the shadow price of constraint L minus the sum of the location j weights multiplied by the j constraint shadow prices:

$$Price_{j=L} = \lambda_L - \sum_j w_j \lambda_j$$

One j constraint shadow price will be zero because the constraint was dropped. The swap price will always be less than or equal to the lowest cleared swap bid at a location.

A.5 Central swap market pool revenue neutrality

Without the relaxation swaps, the central swap market pool is revenue neutral. We already know from Section A.1 that the spot market payments sum to zero. Here we show that the net forward market payments also sum to zero. The net forward market payments are the cleared swap multiplied by the swap prices:

$$Net\ market\ payments = \sum_{i,j} S_{i,j} Price_j = \sum_{i,j} S_{i,j} \left(\lambda_j - \sum_j w_j \lambda_j \right) = \sum_j \lambda_j \left(\sum_{i \in j} S_{i,j} - w_j \sum_{i,j} S_{i,j} \right)$$

The market trade balance constraints are:

$$\sum_{i \in j} S_{i,j} - w_j \sum_i S_{i,j} = 0 \quad \forall\ j$$

Therefore, at the market clearing values of $S_{i,j}$:

$$Net\ market\ Payments = \sum_j \lambda_j (0) = 0$$

The central swap market pool is revenue neutral without swap relaxations. Adding relaxation swaps would also relax revenue neutrality. A rule to distribute net payments back to pool participants would restore revenue neutrality. The swap pool is revenue neutral because, for each trade balance constraint, quantity demanded from market participants equals quantity supplied by market participants and all participants trade at the same market price.