Real-time Revenue Imbalance in CAISO Markets

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This discussion paper relates to analysis of real-time imbalance offset costs in Section 3.4 of the Department of Market Monitoring's 2012 Annual Report. This paper provides more mathematical details of the methods used in this analysis, as well as more in-depth explanations of many of the underlying concepts and issues.

The primary objective of the paper is to explain an analytical framework for analyzing and quantifying the causes of real-time imbalance offset charges. Another objective is to apply that framework to analyze the contribution of virtual bidding to real-time imbalance offset charges. The final objective is to use this framework and analysis to suggest a potential cost allocation method for real-time imbalance offset that may mitigate problems created by the contribution of virtual bidding to these uplift costs.

The real-time imbalance offset is a charge allocated to load serving entities to make the ISO whole for real-time market revenue imbalances. The energy settled in the real-time market for a demand or supply resource is the difference between the resource's schedule in the day-ahead market and the resource's schedule in the relevant real-time market. The real-time imbalance offset charge is the difference between the total money paid out by the ISO and the total money collected by the ISO for energy settled at hour-ahead and 5-minute market prices.

The real-time imbalance offset charge consists of two components. Any revenue imbalance from the energy and loss components of hour-ahead and 5-minute market real-time energy settlement prices is collected through the *real-time imbalance energy offset charge* (RTIEO). Any revenue imbalance from just the congestion components of these real-time energy settlement prices is recovered through the *real-time congestion imbalance offset charge* (RTCIO).

High real-time imbalance offset charges can be an indicator of market inefficiencies. In addition, these uplift charges represent transactions that are not accurately reflected in market prices. Therefore, while some offset charges will inevitably result from uncertainties and fluctuations in real-time conditions, the ISO should work to reduce these out-of-market uplifts.

Real-time imbalance costs for energy and congestion were roughly $165 million in 2011 and increased to around $235 million in 2012. The rest of this paper explains the structural causes of these charges, analyzes the role of virtual schedules in contributing to these costs, suggests actions for reducing these costs, and suggests methods that may be used for more equitably allocating these costs.

1 Decomposing real-time imbalance offset into energy and congestion components

To analyze the causes of real-time imbalance offset charges when there are two real-time markets (5-minute and hour-ahead), we differentiate between nodes that settle deviations between day-ahead and real-time schedules based on their 5-minute market LMP and nodes that settle such deviations on their hour-ahead market LMP. We designate the (internal) nodes that settle on 5-minute market prices as $r \in \{R\}$. We designate the (intertie) nodes that settle on hour-ahead prices as $h \in \{H\}$. The total real-time imbalance offset charge for a 5-minute interval is therefore:[1]

$$RTIO = \sum_r \left[LMP_r^{5\min} * Q_r^{5\min-DA} \right] + \sum_h \left[LMP_h^{HASP} * Q_h^{HASP-DA} \right] \qquad (1)$$

Where $Q_i^{MARKET-DA}$ is 1/12 the scheduled net power injection at node *i* in the designated real-time market run minus 1/12 the day-ahead market's net power injection at node *i*. LMP_i^{MARKET} is the price at node *i* in the designated real-time market. A net generation or supply is a positive net injection, while a net load or demand is a negative net injection. Note that a positive RTIO value in equation (1) means the market has paid out more money than it brought in, so the RTIO is a charge that must be allocated to market participants to pay out-of-market.

By decomposing LMP into its three standard components (system energy, loss, and congestion), equation (1) can be rewritten as:

$$RTIO = \sum_r \left[SMEC_r^{5\min} * Q_r^{5\min-DA} \right] + \sum_h \left[SMEC_h^{HASP} * Q_h^{HASP-DA} \right] + \qquad (2.1)$$

$$\sum_r \left[LOSS_r^{5\min} * Q_r^{5\min-DA} \right] + \sum_h \left[LOSS_h^{HASP} * Q_h^{HASP-DA} \right] + \qquad (2.2)$$

$$\sum_r \left[CONG_r^{5\min} * Q_r^{5\min-DA} \right] + \sum_h \left[CONG_h^{HASP} * Q_h^{HASP-DA} \right] \qquad (2.3)$$

The sum of terms (2.1) and (2.2) is the real-time imbalance energy offset charge. Term (2.3) is the real-time congestion imbalance offset charge.

2 Real-time imbalance energy offset

Real-time imbalance energy offset charges are primarily a function of two factors: (1) the quantity of net import (or export) energy, including liquidated intertie virtual schedules, the ISO buys (or sells) in the hour-ahead market in a given hour, and (2) the difference between system energy prices in the hour-ahead and 5-minute real-time markets.

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[1] This assumes all resources perform at their real-time schedules and that each resource's energy for each interval is settled on that interval's LMP. The contribution of uninstructed deviation to RTIO can easily be added onto the framework discussed in this paper. Different resources settling on LMPs and schedules averaged over different lengths of time granularity affects the RTIO as well. These impacts, along with others, are quantified below as 'Other causes'. The author separately studied the impacts of different settlement time granularity on RTIO, and found that those impacts were small compared to the causes discussed in this paper.

The quantity of net intertie energy bought (or sold) by the ISO at the hour-ahead market price must be offset by the ISO through an equal but opposite quantity of internal energy sold (or bought) at the 5-minute market prices. This is because the hour-ahead optimization makes adjustments to the day-ahead schedules of demand and supply resources to equate system-wide supply and demand. The hour-ahead market makes adjustments to the day-ahead schedules of intertie imports and exports as well as to the day-ahead schedules of internal load and generation resources. Given that total supply must equal total demand in the hour-ahead market, any overall change to the day-ahead schedules of *intertie* resources (including the zeroing out of all intertie virtual schedules) in the hour-ahead market must be offset by an equal but opposite overall change to the day-ahead schedules of *internal* resources (including changes to load and the zeroing out of all internal virtual schedules) in the hour-ahead market. While the change to the day-ahead schedules of intertie resources settle on the hour-ahead system energy prices, the equal but opposite change to the day-ahead schedules of internal resources in the hour-ahead market settles on the 5-minute market system energy prices. When hour-ahead market system energy prices are different than 5-minute market system energy prices, the offsetting change to internal and intertie schedules creates a revenue imbalance that is allocated as either a charge or credit to the real-time imbalance energy offset account.[2]

The ISO can therefore reduce the magnitude of the (positive or negative) uplift in any given hour by either (1) reducing the quantity of net intertie energy it acquires that hour, or (2) by reducing the system energy price difference between the hour-ahead and 5-minute markets.

The difference between prices in the hour-ahead and 5-minute markets did not decrease significantly in 2012.[3] However, the quantity of net energy sold in the hour-ahead market was significantly lower in 2012, as shown in Figure 1.

Suspension of virtual bids at the interties in November of 2011 contributed significantly to the reduction in this volume. This played a major role in decreasing the real-time imbalance energy offset charge from $50 million in 2012 to $137 million in 2011. Eliminating settlements in the hour-ahead market and settling all internal and intertie schedules (including virtual schedules) on a 15-minute market should eliminate most real-time imbalance energy offset charges.[4]

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[2] The 5-minute market will subsequently make changes to the hour-ahead market schedules of internal physical supply and demand resources. Note that the 5-minute market will not make any changes to the hour-ahead market schedules of any virtual schedules because virtual schedules are 0 in all hour-ahead and 5-minute market runs. In each 5-minute market, system-wide supply must again equal system-wide demand. Therefore, all changes to the hour-ahead market schedules of physical internal resources in each 5-minute market will offset at the same 5-minute market system energy price (notwithstanding some changes to the hour-ahead schedules of intertie nodes in the 5-minute market, discussed below in the section on real-time congestion imbalance offset). Therefore, this will not significantly impact real-time imbalance *energy* offset costs.

[3] See Chapter 2 of the Department of Market Monitoring 2012 Annual Report.

[4] The ISO proposed such a settlement scheme in its FERC Order 764 Compliance Draft Final Proposal available at: http://www.caiso.com/Documents/DraftFinalProposal-FERC-Order764MarketChanges.pdf

Figure 1:   Physical and virtual energy settled in hour-ahead market
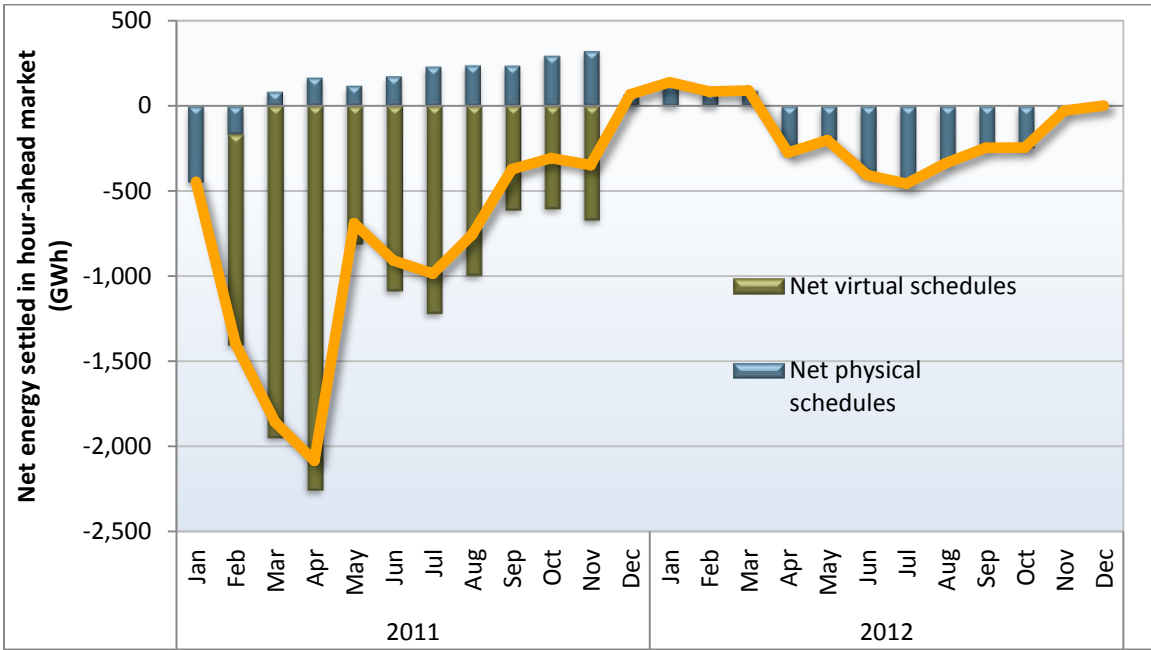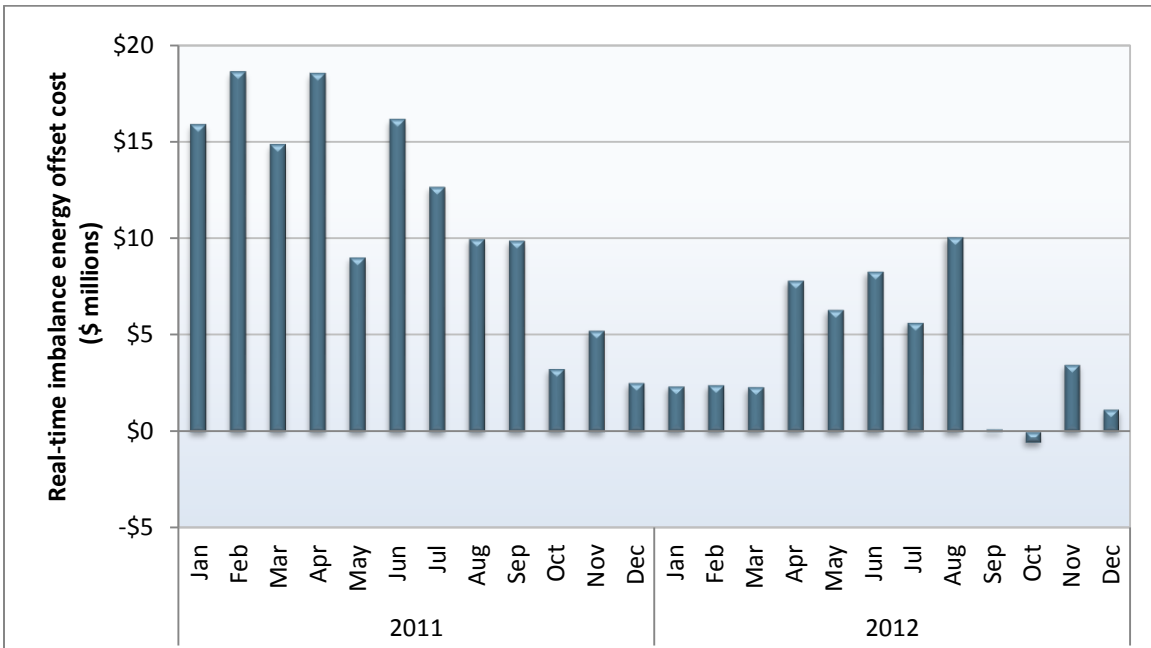

Figure 2:   Real-time imbalance energy offset costs

3   Real-time congestion imbalance offset

This section presents an analysis performed to estimate the contribution to real-time congestion imbalance offset from various factors. The analysis estimates each constraint's contribution to these costs and divides causation into four separate categories:

- Decreases in power flow limits between day-ahead and hour-ahead markets,

- Decreases in power flow limits between hour-ahead and 5-minute markets,

- Differences in constraint shadow prices in the hour-ahead and 5-minute markets, and

- Changes to intertie resources' hour-ahead schedules in the 5-minute market.

A more detailed description of these four contributing factors and results of this analysis are provided below.

3.1   Decomposing real-time congestion imbalance offset into contribution from each constraint

As discussed above, the real-time congestion imbalance offset charge is:

$$RTCIO = \sum_r \left[CONG_r^{5\min} * Q_r^{5\min-DA} \right] + \sum_h \left[CONG_h^{HASP} * Q_h^{HASP-DA} \right] \tag{3}$$

The real-time congestion imbalance offset charge can be further decomposed into the precise contribution from each constraint. Given that a node's congestion component of LMP in a particular market is the sum of the contribution of all binding constraints, *L*, in that market:

$$CONG_i^{MARKET} = \sum_L - SF_{i,L}^{MARKET} * \lambda_L^{MARKET} \tag{4}$$

equations (3) and (4) can be combined to obtain:

$$RTCIO = \sum_r \left[\sum_L - SF_{r,L}^{5\min} * \lambda_L^{5\min} * Q_r^{5\min-DA} \right] + \sum_h \left[\sum_L - SF_{h,L}^{HASP} * \lambda_L^{HASP} * Q_h^{HASP-DA} \right] \tag{5}$$

Where $SF_{i,L}^{MARKET}$ is the shift factor of node *i* with respect to constraint *L* in the designated market, and λ_L^{MARKET} is the shadow price of constraint *L* in the designated market.

If we rearrange the summations of equation (5) to first sum over nodes (inner summation) and then to sum over constraints (outer summation), we obtain the definition of the real-time congestion imbalance offset charge as a sum of contributions from every constraint that has a non-zero shadow price in either the 5-minute or hour-ahead market:

$$RTCIO = \sum_L \left[\sum_r - SF_{r,L}^{5\min} * \lambda_L^{5\min} * Q_r^{5\min-DA} + \sum_h - SF_{h,L}^{HASP} * \lambda_L^{HASP} * Q_h^{HASP-DA} \right] \tag{6}$$

The contribution to the RTCIO from a single constraint is therefore:

$$RTCIO_L = \sum_r \left[-\lambda_L^{5\min} * SF_{r,L}^{5\min} * Q_r^{5\min-DA} \right] + \sum_h \left[-\lambda_L^{HASP} * SF_{h,L}^{HASP} * Q_h^{HASP-DA} \right] \qquad (7)$$

Equation (7) states that the contribution of a constraint to the RTCIO is a two-step process. First, multiply each node's real-time deviation from its day-ahead schedule by the constraint's contribution to each node's Congestion component of LMP. This gives the constraint's contribution to each node's contribution to the RTCIO charge. Second, sum this product over all nodes to get the constraint's total contribution to the RTCIO charge.

3.2   Decomposing constraint contribution to RTCIO into four causes

Equation (7) provides the most direct method for calculating a constraint's contribution to the RTCIO. However, the terms are not particularly useful for analyzing what caused the constraint to contribute to the RTCIO. Below, we perform some algebraic manipulation to equation (7) in order to express the equation in a form that lends itself to more meaningful analysis.

First, it is true that:[5]

$$0 = -\sum_r \left[\lambda_L^{5\min} * SF_{r,L} * Q_r^{HASP} \right] + \sum_r \left[\lambda_L^{5\min} * SF_{r,L} * Q_r^{HASP} \right] \quad (8)$$

After expanding the first term of Equation (7) and adding Equation (8), Equation (7) can be rewritten as:

$$RTCIO_L = \sum_r \left[-\lambda_L^{5\min} * SF_{r,L} * Q_r^{5\min} \right] + \qquad\qquad (9.1)$$

$$\sum_r \left[-\lambda_L^{5\min} * SF_{r,L} * \left(-Q_r^{DA} \right) \right] + \qquad\qquad (9.2)$$

$$\sum_h \left[-\lambda_L^{HASP} * SF_{h,L} * Q_h^{HASP-DA} \right] + \qquad\qquad (9.3)$$

$$-\sum_r \left[\lambda_L^{5\min} * SF_{r,L} * Q_r^{HASP} \right] + \qquad\qquad (9.4)$$

$$+\sum_r \left[\lambda_L^{5\min} * SF_{r,L} * Q_r^{HASP} \right] \qquad\qquad (9.5)$$

Next, combine term (9.2) with (9.4), leave term (9.3) alone, and combine term (9.1) with (9.5) to obtain:

$$RTCIO_L = -\lambda_L^{5\min} \sum_r \left[SF_{r,L} \left(Q_r^{HASP} - Q_r^{DA} \right) \right] + \qquad\qquad (10.1.1)$$

$$-\lambda_L^{HASP} \sum_h \left[SF_{h,L} \left(Q_h^{HASP} - Q_h^{DA} \right) \right] + \qquad\qquad (10.1.2)$$

$$-\lambda_L^{5\min} \sum_r \left[SF_{r,L} \left(Q_r^{5\min} - Q_r^{HASP} \right) \right] \qquad\qquad (10.2)$$

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[5] This decomposition method can be expanded to include terms that assign RTCIO causation to changes in shift factors between markets. However, availability of shift factor data forced the analysis in this paper to be limited to assuming shift factors were the same in all markets. Topology changes between markets are instead accounted for as one potential source of a change in a constraint's real-power flow capacity, discussed below.

Terms (10.1.1) and (10.1.2) quantify the constraint's contribution to RTCIO from changes in the constraint's flow limit between the day-ahead and hour-ahead markets, and from differences between hour-ahead and 5-minute market shadow prices. Term (10.2) quantifies the constraint's contribution to RTCIO from changes in the constraint's flow limit between the hour-ahead and 5-minute markets and from changes to intertie resources' hour-ahead schedule in the 5-minute market.

Decrease in power flow limits between day-ahead and hour-ahead markets

When the scheduled power flow over a constraint decreases between the day-ahead and hour-ahead markets, this change in power flow must be accomplished by an increase in net power injections at some nodes, and an equal quantity of decreased net power injections at other nodes.[6] Net power injections must increase at nodes where an injection has a relatively high effectiveness at reducing power flows over the constraint. Net power injections must decrease at nodes where a withdrawal has a relatively high effectiveness at reducing power flows over the constraint.

The constraint's impact on the real-time price of each injection or withdrawal is directly proportional to the effectiveness of the injection or withdrawal in impacting flow on the constraint. A constraint's congestion price will have a positive impact on the price at locations where an injection would reduce flow on the constraint. Conversely, a constraint's congestion price will have a negative impact on the price at nodes where a withdrawal would reduce flow on the constraint.

To reduce the day-ahead flow on the constraint to the lower hour-ahead limit, the extra hour-ahead injections must be at locations with higher overall prices than the equal quantity of withdrawals. Reducing flow limits on constraints between the day-ahead and hour-ahead market therefore causes the ISO to buy power at a high price in real-time while simultaneously selling the same quantity of power back at a relatively low price in real-time. This creates the real-time revenue imbalance.

This decrease in flow between the day-ahead and hour-ahead markets is accomplished by a combination of changes to day-ahead schedules at internal nodes and intertie nodes. The changes to day-ahead schedules of internal nodes that contribute to meeting this flow change contribute to real-time congestion imbalance offset based on the 5-minute market shadow price of the constraint. The changes to day-ahead schedules of intertie nodes that contribute to meeting this flow change contribute to the real-time congestion imbalance offset based on the hour-ahead market shadow price of the constraint.

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[6] The changes in flow limits discussed throughout the real-time congestion imbalance offset sections of this paper refer specifically to the changes between the linearized real-power flow quantities that settle on the constraint's shadow price. The changes to these real-power flow limits may be caused by manual adjustments to the constraint's alternating current power flow limit used in the markets. Other structural differences between the markets may cause differences in the amount of constraint capacity available for real power settled in the markets. These other structural differences include reactive power flow differences between markets; different impacts from compensating injections in the different markets; and topography changes between markets (such as an outage of line X after the day-ahead market that causes the shift factors for constraint Y to be different between the day-ahead and real-time).

Differences in hour-ahead and 5-minute market shadow prices

For any given hour, the impact on the constraint's hour-ahead market flows from changes to day-ahead schedules of *internal* nodes (the non-shadow price portion of 10.1.1) may be in the opposite direction as the flow impact from changes to day-ahead schedules of *intertie* nodes (the non-shadow price portion of 10.1.2). Therefore, some of the flow impact on the constraint from internal nodes *offsets* the flow impact from intertie nodes. In such an hour, the amount of the internal node flow impact and intertie node flow impact that is offsetting does not contribute to decreasing the day-ahead market flow down to the lower hour-ahead market flow level. However, the flow impact from internal nodes settles on the constraint's 5-minute market shadow price while the offsetting amount of flow impact from intertie nodes settles on the constraint's hour-ahead market shadow price. As a result, each MWh of offsetting internal/intertie flow impact contributes to the real-time congestion imbalance offset. The dollar per MWh contributed to the real-time congestion imbalance offset is the difference between the hour-ahead and 5-minute market shadow prices.

Therefore, when the flow impact on the constraint from internal nodes is in the same direction as the flow impact from intertie nodes, the entirety of (10.1.1) and (10.1.2) is attributed to differences in flow limits between the day-ahead and hour-ahead markets. However, when the flow impact from internal nodes is in the opposite direction as the flow impact from intertie nodes, the offsetting portion must be attributed to different hour-ahead and 5-minute shadow prices.[7] Only the net portion can be attributed to different day-ahead and hour-ahead flow limits.[8]

Decreases in power flow limits between hour-ahead and 5-minute markets

A constraint's power flow can also be decreased between an hour's hour-ahead market and 5-minute market runs. This incrementally increases the real-time congestion imbalance offset through the same dynamic described above for changes to day-ahead and hour-ahead constraint limits. The main difference is that the decrease in flow between the hour-ahead and 5-minute markets is almost entirely accomplished by changes to the hour-ahead schedules of internal nodes.[9] The changes to hour-ahead schedules of internal nodes that contribute to meeting this flow change contribute to real-time congestion imbalance offset based on the 5-minute market shadow price of the constraint.

Changes to intertie resources' hour-ahead schedules in the 5-minute market

The hour-ahead schedules of non-dynamic intertie resources settle on the resource's hour-ahead market price. While the settlement quantity of such resources does not deviate from the

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[7] At a dollar per MWh rate equal to the difference between the shadow prices.

[8] At a dollar per MWh rate equal to the 5-minute shadow price when there is a net flow impact from internal nodes, and a dollar per MWh rate equal to the hour-ahead shadow price when there is a net flow impact from intertie nodes.

[9] Intertie resources for the most part have the same schedules in the hour-ahead and 5-minute markets. The contribution to real-time congestion imbalance offset from non-dynamic system resources that have different schedules in the 5-minute market than in the hour-ahead market is discussed in the final two descriptions of the causes of real-time congestion imbalance offset immediately below.

hour-ahead schedule,[10] the 5-minute market will change the unpublished schedule of these resources to account for issues such as inter-hour ramp. Similar to the dynamic described above,[11] for any given interval, the impact on the constraint's 5-minute market flows from changes to hour-ahead schedules of *internal* nodes may be in the opposite direction as the flow impact from changes to hour-ahead schedules of *intertie* nodes. In such an interval, the amount of the internal node flow impact that is offset by intertie flow impact does not contribute to decreasing the hour-ahead market flow down to the lower 5-minute market flow level. We therefore attribute the real-time congestion imbalance offset contribution from this quantity of internal node flow impact to the fact that the market design allows unsettled changes to intertie hour-ahead market schedules in the 5-minute market.

Other causes not specifically identified in our analysis

Our analysis accounts for most causes of real-time congestion imbalance offset that are related to scheduled market quantities and prices. The analysis does not account for manual changes to market awards and prices (with the exception of some shadow price corrections that are included in the analysis). The causes of real-time congestion imbalance offset quantified in the 'Other causes' category therefore include some price corrections to shadow prices, uninstructed and unaccounted-for energy, and operational adjustments to system resources' hour-ahead schedules that settle on 5-minute market prices.

3.3   Decomposing RTCIO under 15-minute market structure

In the FERC Order 764 Compliance 15-Minute Scheduling and Settlement Draft Final Proposal, the ISO has proposed to eliminate settlements in the hour-ahead market. Instead, the current RTPD will produce schedules for all internal and intertie load and generation resources every 15 minutes. All internal and intertie virtual schedules will liquidate in the 15-minute market, and the difference between the day-ahead and 15-minute schedules of all internal and intertie resources (load, generation, and virtual) will settle on the 15-minute market LMPs.

Under this 15-minute market structure, the decomposition of constraint contribution to RTCIO will become much more straightforward. The equivalent of equation (10) under this 15-minute market structure is simply:

$$RTCIO_L = -\lambda_L^{15\min} \sum_{i \in \{R\} \cup \{H\}} \left[SF_{i,L} \left(Q_i^{15\min} - Q_i^{DA} \right) \right] + \qquad (11.1)$$

$$-\lambda_L^{5\min} \sum_r \left[SF_{r,L} \left(Q_r^{5\min} - Q_r^{15\min} \right) \right] \qquad (11.2)$$

Term (11.1) quantifies the constraint's contribution to RTCIO from changes in the constraint's flow limit between the day-ahead and 15-minute markets. Term (11.2) quantifies the constraint's contribution to RTCIO from changes in the constraint's flow limit between the 15-minute and 5-minute markets and from changes to intertie resources' 15-minute market schedule in the 5-minute market.

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[10] This is true unless there are operational adjustments, which are discussed below in the 'Other causes' section.

[11] See section on 'Differences in hour-ahead and 5-minute market shadow prices'.

3.4   Results of analysis

Real-time congestion imbalance offset costs increased from about $30 million in 2011 to over $185 million in 2012. As shown in Figure 3, results of this analysis indicate that reductions in power flow limits of constraints between day-ahead and real-time caused about $155 million of the $185 million of real-time congestion imbalance offset charges in 2012.

Figure 3:   Causes of real-time congestion imbalance offset costs by year
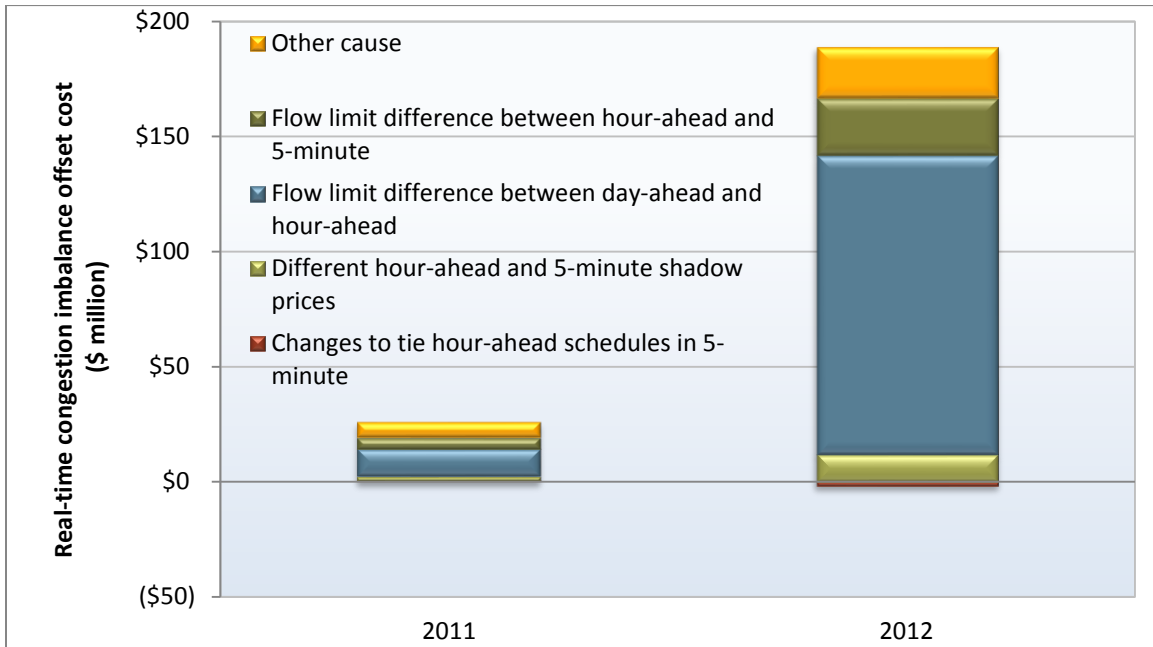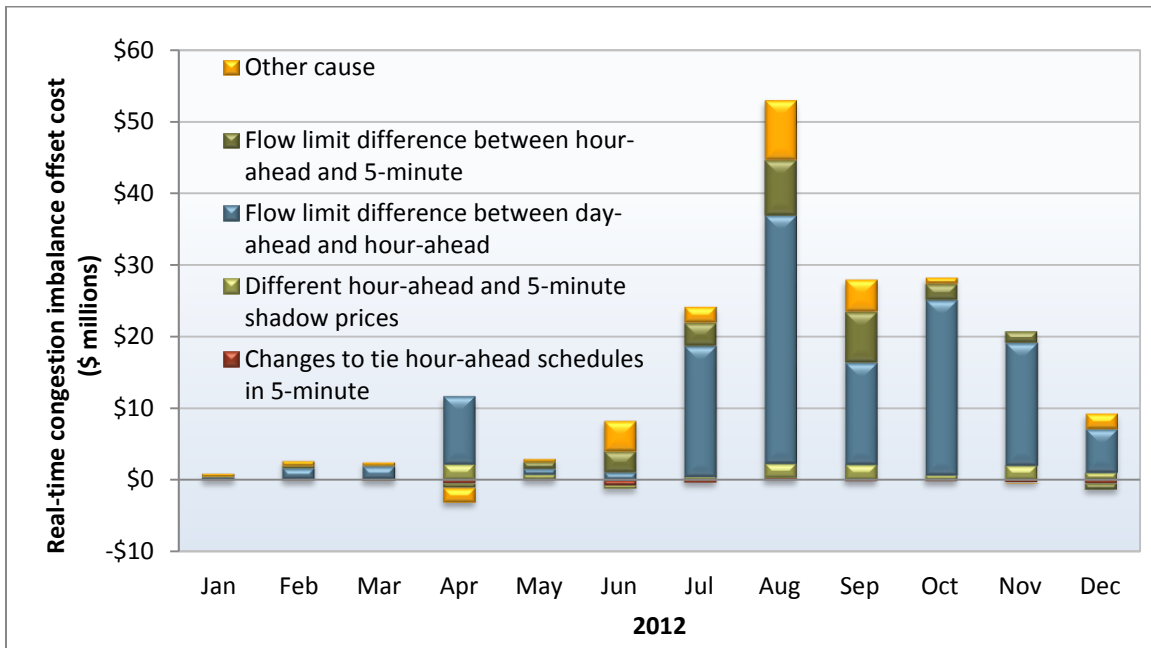

Figure 4 illustrates that changes to these power flow limits between markets was consistently the main cause of the real-time congestion imbalance offset costs in 2012, accounting for the bulk of the cost in every month.

Figure 4:   Causes of real-time congestion imbalance offset by month in 2012

3.5   Results by constraint

Results of this analysis show that a large portion of the high uplift charges caused by reductions in power flow limits after the day-ahead market was driven by a handful of constraints. Figure 5 illustrates that the top seven constraints contributed about 60 percent of the real-time congestion offset costs caused by reducing constraints' power flow limits after the day-ahead market in 2012. However, about 30 other constraints each contributed more than $500,000 to these costs, and over 40 more constraints each contributed more than $100,000 each to this uplift.

Intertie system resources significantly impacted the congestion on the top seven constraints in Figure 5. Reducing the power flow limits of such constraints down after the start of the hour-ahead market run prevents the 15-minute pre-dispatch and 5-minute real-time dispatch optimizations from re-dispatching some of the resources that are most effective at reducing the constraints' flows. As a result, reducing the power flow limits of constraints down after the start of the hour-ahead market run can significantly increase the magnitude of the congestion price of these constraints in the 5-minute market.

This can amplify the impacts of even small reductions in the constraint's power flow limit after the hour-ahead market. This is because it is not just the additional changes to internal nodes' 5-minute market schedules relative to the internal nodes' hour-ahead schedules that contribute to real-time congestion imbalance offset based on the constraint's 5-minute market shadow price. As explained above, all changes to internal nodes' day-ahead schedules in either the hour-ahead or 5-minute markets (including all internal virtual schedules that liquidate in the hour-ahead market) contribute to the real-time congestion imbalance offset based on the 5-minute market shadow price of the constraint.

Eliminating settlements in the hour-ahead market and settling all internal and intertie schedules (including virtual schedules) on a 15-minute market should reduce the real-time congestion imbalance offset charge. This is because all flow changes between the day-ahead and 15-minute markets will settle on the shadow price produced by the 15-minute market. However, the real-time congestion imbalance offset charge will still be a large source of out-of-market uplift payment if power flow limits continue to be lower in the real-time markets than in the day-ahead. In order to reduce the real-time congestion imbalance offset charge, the ISO should continue to refine its methods for setting constraints' day-ahead capacity for real-power flow at constraints' expected real-time capacity.

Figure 5:   Distribution by constraint of real-time congestion imbalance offset costs caused by changes to constraints' power flow limits (2012)
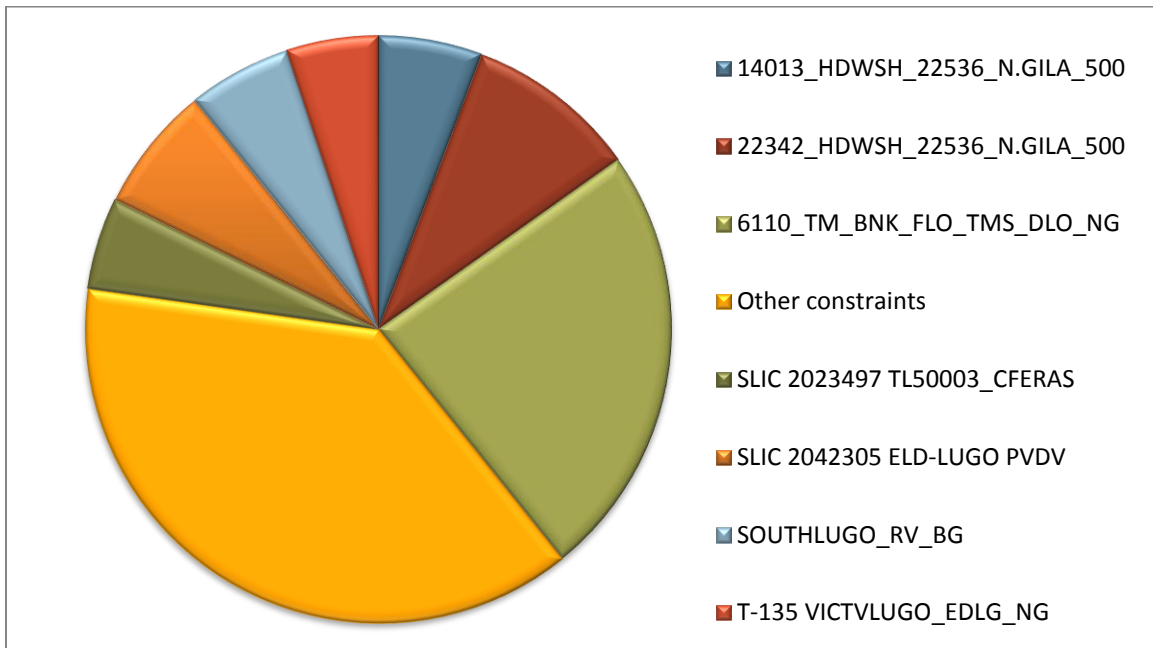

Legend:
- 14013_HDWSH_22536_N.GILA_500
- 22342_HDWSH_22536_N.GILA_500
- 6110_TM_BNK_FLO_TMS_DLO_NG
- Other constraints
- SLIC 2023497 TL50003_CFERAS
- SLIC 2042305 ELD-LUGO PVDV
- SOUTHLUGO_RV_BG
- T-135 VICTVLUGO_EDLG_NG

Table 1: Real-time congestion imbalance offset costs caused by changes to constraints' power flow limits (top 30 constraints of 2012)

Constraint	2012 RTCIO caused by differences between DA and RT flow limits
6110_TM_BNK_FLO_TMS_DLO_NG	$37,700,000
22342_HDWSH _500_22536_N.GILA _500_BR_1 _1	$14,800,000
SLIC 2042305 ELD-LUGO PVDV	$10,700,000
SOUTHLUGO_RV_BG	$9,500,000
14013_HDWSH _500_22536_N.GILA _500_BR_1 _1	$8,600,000
SLIC 2023497 TL50003_CFERAS	$8,100,000
T-135 VICTVLUGO_EDLG_NG	$8,000,000
SCIT_BG	$6,400,000
SDGE_CFEIMP_BG	$6,000,000
BARRE-LEWIS_NG	$5,100,000
PACI_ITC	$4,400,000
SCE_PCT_IMP_BG	$3,400,000
SLIC 1953261 ELD-LUGO PVDV	$2,800,000
SLIC 1902749 ELDORADO_LUGO-1	$2,700,000
7820_TL 230S_OVERLOAD_NG	$2,400,000
SLIC 1356092 Serrano Valley OUT	$2,300,000
SLIC 1884984 Gould-Sylmar	$2,000,000
NOB_ITC	$2,000,000
24137_SERRANO _230_24154_VILLA PK_230_BR_1 _1	$1,900,000
230S overload for loss of PV	$1,800,000
T-167 SOL 2_NG_SUM	$1,700,000
PATH26_N-S	$1,700,000
T-165 SOL-12_NG_SUM	$1,600,000
SLIC 1956086_ELD-MCCUL HDW	$1,600,000
22356_IMPRLVLY_230_22360_IMPRLVLY_500_XF_80	$1,600,000
PATH15_S-N	$1,500,000
24086_LUGO _500_26105_VICTORVL_500_BR_1 _1	$1,400,000
30550_MORAGA _230_33020_MORAGA _115_XF_3 _P	$1,200,000
MEAD_ITC	$1,100,000
T-165 SOL-4_NG_SUM	$1,100,000

4 Virtual bidding and real-time imbalance offset costs

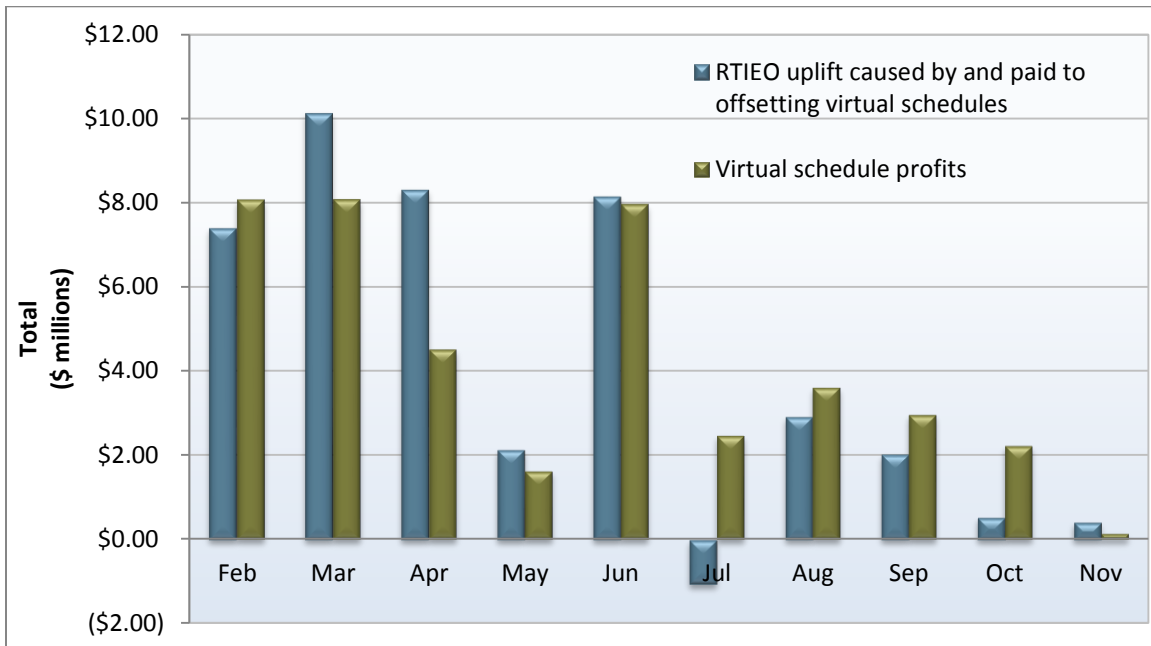## 4.1 Virtual bidding and real-time imbalance energy offset costs

As described in Section 2 above, intertie virtual schedules contributed to increasing real-time imbalance energy offset charges in 2011 by increasing the amount of energy that settled in the hour-ahead market. The net cleared quantity of intertie virtual schedules interacts with other product types to create the real-time imbalance energy offset charge. Therefore, it may not be accurate to use the net cleared quantity of intertie virtual schedules to quantify the amount of RTIEO directly caused by intertie virtual schedules. However, the portion of net intertie virtual schedules that is offset by net internal virtual schedules causes real-time imbalance energy offset charges that are attributable to virtual schedules alone.

Virtual supply cleared on an intertie node pays the system energy price from the hour-ahead market when liquidating in real-time. However, virtual demand cleared on an internal node receives the system energy price from the 5-minute market when liquidating in real-time. Therefore, every MWh of net intertie virtual supply that is offset by a MWh of net internal virtual demand contributes the difference between the 5-minute market and hour-ahead market system energy prices to the real-time imbalance energy offset charge. Similarly, virtual schedules directly cause a charge or credit to the RTIEO during hours when intertie virtual demand exceeds intertie virtual supply, and internal virtual supply exceeds internal virtual demand. During such hours, every MWh of net intertie virtual demand that is offset by a MWh of net internal virtual supply contributes the difference between the hour-ahead market and 5-minute market system energy prices to the real-time imbalance energy offset charge.

Figure 6 compares the uplift caused by offsetting virtual schedules to the profits[12] from all virtual schedules between February and November, 2011. During this time period, offsetting virtual schedules caused roughly $41 million in real-time imbalance energy offset charges. Meanwhile, the profits from all virtual schedules were about $42 million. Out-of-market RTIEO uplift paid by load but which were received by virtual schedules and that were directly caused by offsetting virtual schedules were sufficient to pay for almost all virtual bidding profits during the 10 months of 2011 when virtual bids were allowed on the interties.

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[12] The virtual bidding profits considered in this paper are the DA revenues minus the RT revenues of virtual schedules. It does not consider administrative charges assigned to virtual bids.

Figure 6: **Virtual schedule profits compared to real-time imbalance energy offset charges caused by and paid to offsetting virtual schedules in 2011**

4.2 Virtual bidding and real-time congestion imbalance offset costs

As discussed above, real-time congestion imbalance offset is caused by underlying differences between ISO markets. The main structural cause of the real-time congestion imbalance offset is differences in power flow limits between the day-ahead and hour-ahead markets, and between the hour-ahead and 5-minute markets. Therefore, virtual schedules increase real-time congestion imbalance offset to the extent that they cause day-ahead power flows to exceed real-time power flows on constraints that bind in real-time.

Analysis designed to assess the real-time congestion imbalance offset charge caused by virtual schedules will be inadequate if the analysis does not appropriately account for the amount of physical day-ahead schedules, and consequently flows, displaced by the cleared virtual schedules. Virtual schedules are cleared in the day-ahead market along with physical schedules and do displace physical schedules to a greater or lesser extent. In the absence of cleared virtual bids, a different amount of physical schedules would clear and contribute to the real-time congestion imbalance offset. A causal analysis would therefore be difficult without re-running the day-ahead market and assessing RTCIO using day-ahead market flows both with and without virtual bids in the market.

However, data from completed market runs can be used to quantify the extent to which cleared virtual schedules, as opposed to cleared physical schedules, benefited from the real-time congestion imbalance offset that actually occurred. We used the analytical framework described above to develop a quantitative method for analyzing virtual schedules' contribution to real-time congestion imbalance offset in 2012.

The method starts by calculating the amount of power flow from virtual schedules over constraints that have different power flows in the day-ahead and real-time markets. However,

virtual schedules' contribution to the real-time congestion imbalance offset is not based on this total virtual flow. The total virtual flow on a constraint simply identifies the virtual schedule flow quantity that settles on the constraint's real-time shadow price.[13]

The difference between a constraint's day-ahead and real-time power flow contributes to a charge or credit to the real-time congestion imbalance offset. The extent to which virtual schedules benefited from real-time congestion imbalance offset payments is therefore limited by the amount the day-ahead market power flow actually exceeded the real-time market power flow of the constraint.[14] This method identifies the amount that virtual schedules contributed to real-time congestion imbalance offset charges (and credits) by only considering the difference between the day-ahead and real-time power flows on each constraint binding in real-time markets.

In particular, when the day-ahead flow exceeds the real-time limit of a constraint binding in real-time and the net impact of all virtual schedules is to increase day-ahead flow on the constraint, virtual schedules *receive* real-time congestion imbalance offset uplift. The real-time congestion imbalance offset uplift *received* by virtual schedules in this situation is the real-time shadow price for each MWh the virtual schedules contributed to increasing the day-ahead flow of the constraint. However, this MWh amount is capped by the amount the day-ahead flow exceeds the real-time flow limit. Similarly, when the real-time flow exceeds the day-ahead flow of a constraint binding in real-time and the net impact of all virtual schedules is to decrease day-ahead flow on the constraint, virtual schedules *pay* a credit to the real-time congestion imbalance offset. The real-time congestion imbalance offset credit *paid* by virtual schedules in this situation is the real-time shadow price for each MWh the virtual schedules contributed to decreasing the day-ahead flow of the constraint. However, this MWh amount is capped by the amount the real-time flow exceeds the day-ahead flow.

Based on this approach, DMM estimates that about $70 million out of $95 million of net real-time congestion revenues paid to virtual positions in 2012 resulted from excess day-ahead power flow on constraints whose power flow limits were reduced between the day-ahead and real-time markets. Moreover, this $70 million paid to virtual schedules from real-time congestion imbalance offset uplift exceeded the $55 million in profits received by virtual schedules in 2012. As a result, the revenues received by virtual schedules that were funded by out-of-market uplift were sufficient to fund all 2012 profits paid to virtual schedules. Figure 7

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[13] The total virtual real-time congestion revenues is what is reported as the 'Virtual' portion of the real-time congestion imbalance offset settlement charge codes. This is not related to how much virtual positions actually contributed to real-time congestion imbalance offset costs, besides through the possible coincidence of the bulk of virtual schedule real-time congestion revenues coming from constraints whose power flow limits are lower in real-time than in the day-ahead. This relationship is discussed below.

[14] When internal and intertie physical and virtual schedules all settle in the 15-minute market, the determination of the RTCIO received by virtual schedules is the straightforward calculation described in the main text. However, with imports and exports currently settling in the hour-ahead market, and internal load, generation, and virtual schedules settling in the 5-minute market, there is more room for interpreting the appropriate calculation of how much RTCIO virtual schedules actually received. The analysis in this paper took a conservative approach that aligned the determination of RTCIO received by virtual schedules with the RTCIO caused by changes in flows. Because virtual schedule flows only change between the day-ahead market and the hour-ahead market, we determined the RTCIO received by virtual schedules to be limited by the total change in the constraint's flows between the day-ahead and hour-ahead markets. We also limit RTCIO received by (or paid to) virtual schedules to the RTCIO charge (or credit) caused by changes between the constraint's total day-ahead flow and the constraint's total hour-ahead flow.

illustrates the monthly estimates and highlights that the real-time virtual bidding contribution to the real-time imbalance offset cost exceeded virtual schedule profits in most months.

Figure 7: **Virtual schedule profits compared to revenues received from real-time congestion imbalance offset uplift in 2012**
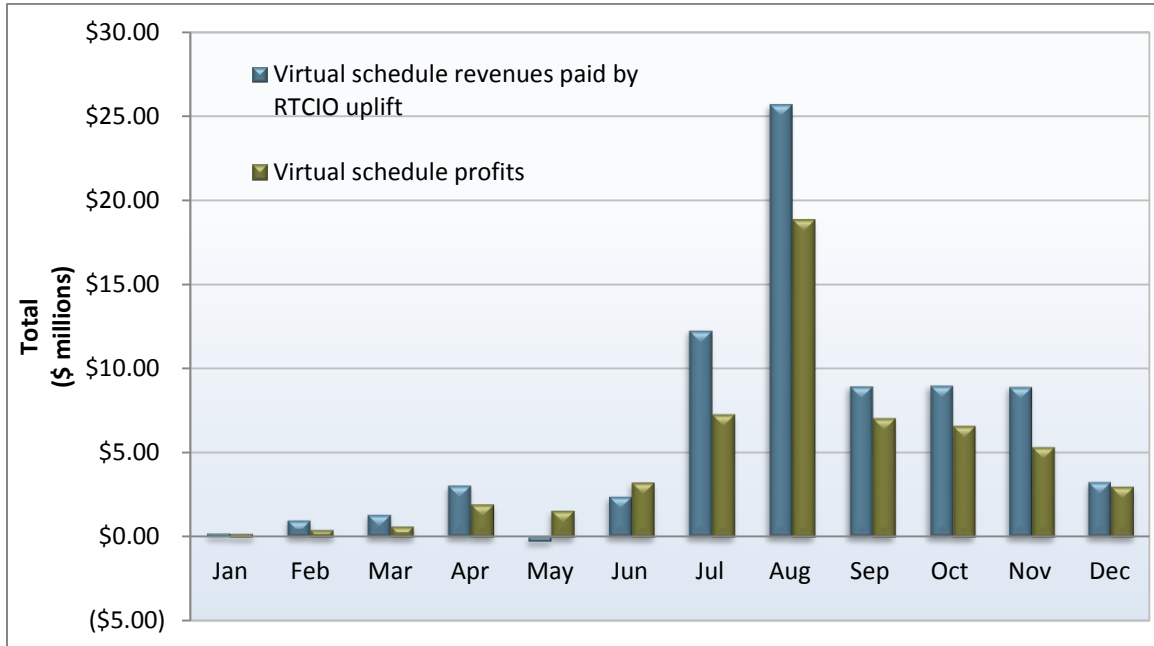
4.3   Allocating real-time congestion imbalance offset charges to virtual schedules

In a market without structural differences between the day-ahead and real-time market models, money paid to virtual schedules for their real-time settlement will be funded by real-time market payments from counterparties that took the opposite position of the virtual schedules in the day-ahead market. However, money paid to virtual schedules that benefit from structural differences between day-ahead and real-time markets is not covered by in-market real-time payments from schedules taking the opposite position. This revenue imbalance results in an uplift charge that is paid by metered demand.

This analysis reveals the significant extent to which virtual schedules were submitted and cleared to leverage constraints modeled with power flow limits that were higher in the day-ahead market than they were in the real-time markets. As a result, the vast majority of real-time congestion revenues paid to virtual schedules were charged to metered demand as uplift. The revenues virtual schedules have received from uplift caused by structural differences between ISO markets has been the cause of virtual schedules being profitable overall since their introduction to CAISO electricity markets in February 2011.

In 2011, real-time imbalance energy offset charges received by virtual schedules and that were directly caused by offsetting virtual schedules were sufficient to pay for almost all virtual bidding profits. In 2012, real-time congestion imbalance offset revenues received by virtual schedules greatly exceeded virtual bidding profits. While virtual bids may play a role in creating some

economic efficiency through converging prices, their profits are overwhelmingly derived from their contribution to creating real-time imbalance offset charges. This creates the perverse incentives for virtual schedules to exacerbate these revenue neutrality deficits, thereby decreasing the extent to which dispatches are accurately reflected in market prices.

In general, allocating cost to the activities that cause it provides the correct incentive to reduce cost to the economically appropriate level. In this case, the fundamental cause does not derive from market participant activities. When this is the case, it is then most appropriate to allocate cost to the activities that benefit from the incurred cost. An alternative to the existing cost allocation that is in line with the benefit approach to cost allocation is to allocate the real-time congestion imbalance offset uplift cost to both physical and virtual schedules. This alternative allocation could utilize the decomposition methodology used in this analysis to define, by constraint and interval, the real-time congestion imbalance offset received by virtual schedules. In particular, virtual schedules could be allocated real-time congestion imbalance offset charges to pay back the revenue imbalance that they received through the market.

The cost allocation method proposed above would align virtual bidding participation in CAISO markets with the expected severity of the underlying structural market causes of real-time congestion imbalance offset charges. Virtual market participants may build bigger risk premiums into their virtual bids that would be adversely impacted by the day-ahead shadow price of constraints that were expected to have bigger discrepancies between their day-ahead and real-time flow limits. As a result, less virtual bids may clear that increased the day-ahead flow on such constraints, and the magnitude of RTCIO would decline. Conversely, virtual bidders may lower their bid-in risk premiums over constraints whose expected discrepancy between day-ahead and real-time flow limits declined.

Finally, this cost allocation should not adversely impact the participation of virtual bids with respect to constraints that are enforced in real-time markets but not in the day-ahead market. This is because there will not be day-ahead congestion on such a constraint that could make a virtual schedule's congestion profits lower than the virtual schedule's allocated RTCIO uplift from the constraint. Therefore, any cost allocation to virtual schedules with respect to such a constraint would at most take away the congestion profits that the virtual schedules had received from their contribution to the real-time congestion imbalance offset. Virtual schedules would be indifferent to this revenue and uplift cost. However, virtual schedules could still profit from the real-time congestion of such a constraint, if the virtual schedule flows exceeded the size of the modeling discrepancy. Such virtual bidding profits would not be paid through real-time congestion imbalance offset uplift. Instead, these profits would appropriately come at the expense of other market participants who had taken the opposite position in the day-ahead market.