Common-Value Auctions with Liquidity Needs: An Experimental Test of a Troubled Assets Reverse Auction

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Preliminary and Incomplete

1 Introduction

On 3 October 2008, the US Congress passed and the President signed the *Emergency Economic Stabilization Act of 2008* (Public Law 110-343). The Act authorizes the US Treasury to purchase up to $700 billion in troubled assets in order to restore liquidity to financial markets. Since its adoption, the Treasury has earmarked approximately $250 billion for direct purchases of bank equity; as much as $450 billion may be available for the purchase of mortgage-related assets. The Act favors the use of market mechanisms such as reverse auctions for purchasing assets, and the government is currently examining alternative auction designs.

This paper is intended to help us understand the outcomes and relative advantages of alternative auction formats.[1] We conducted laboratory tests of sealed-bid and dynamic clock auction formats during the period October 12-24, 2008, using commercial auction software customized for the purpose. The experimental environments are closely tailored to the likely settings of the planned auctions of troubled assets. In particular, each security has a pure common value, bidders have asymmetric information about the common value, the auctioneer's reference price for each security—reflecting the government's best estimate of the security's value—is based on limited information, and multiple securities are purchased simultaneously in the same reverse auction. The human subjects bidding in the auctions are sophisticated and experienced PhD students, highly motivated by the prospect of earning roughly $800 each—the actual amount depending on performance—for participating in eight experimental sessions over the two-week period.

Several conclusions emerge from the experiments.

- The auctions are competitive. Owing to the bidders' liquidity needs, the Treasury pays less than the true common value of the securities under either format.
- The sealed-bid auction is more prone to bidder error.

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[1] See Ausubel and Cramton (2008) for an analysis of auction design issues in this setting.

- The dynamic clock auction enables bidders to manage their liquidity needs better.
- The bidders attain higher payoffs (trading profits plus liquidity bonus) in the clock auctions than in the sealed-bid auctions.
- Nevertheless, the clock auctions result in equivalent aggregate expenditures, so that the benefit to the bidders does not come at the taxpayers' expense.
- The prices resulting from the clock auctions are a better indication of true values than those from the sealed-bid auctions. Thus, the clock auction is apt to reduce risk for both banks and the Treasury, and to generate price information that may help to unfreeze the secondary markets.

Thus, the clock auction is a win-win for the banks and the taxpayers. The banks attain higher payoffs than in the sealed-bid auction, resulting from better liquidity management. The taxpayers are also better off, as the auction program is better directed toward the liquidity needs of the banking sector without increasing the cost of the auction program. The variability of outcomes is also reduced and the informativeness of prices is also increased with the clock format.

More broadly, the experiments demonstrated the feasibility for quick implementation. The commercial auction platform was customized to handle both formats in one week. Both formats are easy to explain to bidders. Sophisticated subjects required only a three-hour training session to understand the setting, the auction rules, and to practice using the software.

2 Description and summary of results from reference-price auctions

This paper reports on laboratory experiments to test and compare alternative auction formats for a troubled asset reverse auction.

In each auction, bidders compete to sell their holdings of eight securities to the Treasury. The value of each security has a common value, which is unknown. Each bidder has an estimate of the common value. A bidder profits by selling securities to the Treasury at prices above the securities' true values. Bidders also have a need for liquidity. The sale of securities to the Treasury is the source of a bidder's liquidity. A bidder is rewarded to the extent the bidder satisfies her liquidity need. Thus, the bidders care about both profits and liquidity.

The main results reported in this preliminary draft concern the pooled auctions, the second of our two experiments conducted to date. The detailed bidder instructions for both experiments appear in Appendices 1 and 2. In the experiments on pooled auctions, the holdings of the eight individual securities are too concentrated for there to be competitive auctions on a security-by-security basis. The main defining features of the pooled auction are as follows:

- Different securities (i.e., securities with different CUSIP numbers) are included within the same auction;
- Before an auction, the Treasury determines and announces its estimate of the value of each security—these are referred to as *reference prices*;
- The prices in the sealed-bid auction, or in each round of the descending-clock auction, are expressed as a percentage of the reference price for each security—these are referred to as *price points*; and

- Clearing occurs when the cost of purchasing the securities offered at a given price point equals the budget allocated for the auction.

Two auction formats are considered:

- *Simultaneous uniform-price sealed-bid*. Bidders simultaneously submit supply curves for each of the securities within the pool. Supply curves are upward-sloping step functions, where prices are expressed as price points (a percentage of the reference price) and quantities are expressed in dollars of face value. The auctioneer then forms the aggregate supply curve and equates it with the Treasury's demand. The clearing price is the lowest rejected offer. All securities offered at price points below the clearing price point are purchased at the clearing price point. Securities offered at exactly the clearing price point are rationed by a proportional rationing rule.
- *Simultaneous descending-clock*. There is a price "clock" indicating the current range of price points. For example, in Round 1, bidders express the quantities that they wish to supply of each security at all price points from 106% to 102%. After Round 1, the auctioneer aggregates the individual bids and informs bidders of the aggregate quantity that was offered at 102%. Assuming that supply exceeded demand, the price is decremented; for example, in Round 2, bidders may express the quantities that they wish to supply of each security at all price points from 102% to 98%. The process is repeated, with the price decremented, bids submitted and quantities aggregated, until supply is made equal to demand. Then, as in the sealed-bid auction, all securities offered at price points below the clearing price point are purchased at the clearing price point, and bids at exactly the clearing price point are rationed by a proportional rationing rule.

Details of the designs are described in Ausubel and Cramton (2008).

The training of subjects and all experimental sessions took place in the Experimental Lab of the University of Maryland's Economics Department. This is a new state-of-the-art facility for conducting economic experiments. Each subject has her own private cubical with computer and necessary software. The subject pool consisted of Ph.D. students at the University of Maryland and George Mason University. The students have taken or are taking an advanced graduate course in game theory and auction theory, and are pursuing degrees in economics, business, computer science, or engineering.

In each session of approximately three hours, 16 bidders, out of a total subject pool of 19 students, participated in four auctions. Each auction had eight bidders (i.e., there were always two auctions conducted in parallel) and the bidders were randomly matched. In Sessions 1 and 3, the auctions were conducted in the following sequence:

1. Sealed-bid auction, with more precise reference prices
2. Clock auction, with more precise reference prices
3. Sealed-bid auction, with less precise reference prices
4. Clock auction, with less precise reference prices

In Sessions 2 and 4, the auctions with less precise reference prices were conducted first.

The experimental design was intended to facilitate a direct comparison of the sealed-bid auction and the descending-clock auction. Before each sealed-bid auction, each bidder learned the realizations of one or more random variables that were relevant to the value of the securities

that she owned. The same realizations of the random variables applied to the clock auction immediately following the sealed-bid. Thus, in successive pairs of experimental auctions, the securities had the same values and the bidders had the same information. Bidders were not provided with any information about the outcome of a given sealed-bid auction before the following clock auction, in order to avoid influencing the behavior in the clock auction.[2]

Bidders' payoffs consisted of the sum of two terms. First, each bidder received trading profits according to the difference between the common value, v, of the security, and the price, p, at which the bidder's securities were purchased. Hence, if the bidder sold a quantity, q, of securities, the bidder's trading profits equaled: $q \cdot (p - v)$. Second, each bidder was randomly assigned a *liquidity need*, L, and received an additional dollar of payoff for each dollar in sales, $q \cdot p$, up to L that the bidder received in a given auction.

At the conclusion of all sessions, each subject received a check equal to a show-up fee of $22 per session plus an amount proportional to her total experimental payoff. The conversion rate from experimental payoff to take-home dollar payoff ($1 take-home per $100k experimental) was announced before any of the sessions. Average take-home pay was $100.43 per session.

The following is a brief summary of the results. In addition, in Appendices 3 and 4, we provide many figures, which display the results from both experiments graphically.

2.1 Feasibility of implementation

One of the points in conducting the experiments was to demonstrate the feasibility and practicality of conducting a computerized auction in which multiple securities are purchased simultaneously. In this regard, both the sealed-bid and descending-clock auctions can be regarded as successfully implemented in a short time.

2.2 Competitiveness of price

Notwithstanding the presence of adverse selection, as a theoretical matter, the price in the auction can be driven below the security's fundamental value to the extent that the bidders have liquidity needs above and beyond their objective of earning trading profits. This was demonstrated in the experiments. In both the sealed-bid and descending-clock auctions, the prices were significantly below the fundamental values of the respective securities. This is seen in the second row (profit) in Table 1. A bidder's mean trading profits were significantly negative under both formats: -693 with the sealed-bid format and -799 with the clock format.

2.3 Frequency of erroneous bids

In a relatively small but clearly noticeable subset of the auctions, bidders submitted what were almost certainly unintentionally low bids ("erroneous bids"). In descending-clock auctions, the harm to a bidder from an erroneous bid was often fairly limited, as the extent of the damage was that the bidder found herself still in the auction at the end of the round. However, in sealed-

[2] Observe that, inherently, information about a clock auction *must* be revealed, as bidders learn aggregate information about Round 1 before the start of Round 2, etc. Thus, it would have been impossible to run the sealed-bid auctions after the clock auctions without influencing the behavior in the sealed-bid auctions.

bid auctions, the harm could be much greater. Thus, one advantage observed of the clock auction was that it helped to insulate bidders from the effects of their own mistakes.

Table 1. Comparison of mean outcomes by auction type

Variable	Auction Type		Result
	Sealed-bid	Clock	
Clearing price point (percent of reference price)	85.22 (0.81)	83.87 (1.18)	No significant difference in mean clearing price points (t-test p-value of 0.3480)
Profit ($k)	-693 (51)	-799 (57)	Profits are significantly less than zero in both cases, but no significant difference in mean profits (t-test p-value of 0.1680)
Liquidity bonus ($k)	3,915 (172)	4,517 (131)	Clock liquidity bonus is significantly larger than sealed-bid liquidity bonus (t-test p-value of 0.0058)
Payoff ($k)	3,222 (146)	3,719 (116)	Clock payoff is significantly larger than sealed-bid payoff (t-test p-value of 0.0083)
Standard deviation of payoff ($k)	1,654	1,312	Higher standard deviation of payoff in sealed-bid than clock (variance ratio test p-value of 0.0095)
Overshooting the liquidity need ($k)	1,984 (290)	905 (154)	Overshooting the liquidity need is less in clock than in sealed-bid (t-test p-value of 0.0014)

Note: Mean value is shown with standard error in parentheses.

2.4 Management of liquidity needs

If separate sealed-bid auctions are conducted simultaneously, the bidder has no way to condition her bidding in one auction on the amount that she is likely to win in other auctions. By contrast, if separate dynamic auctions are conducted simultaneously, the bidder can observe the outcome evolving in one auction and use that information to adjust her behavior in other auctions. Thus, the bidder has much greater ability to manage her liquidity need, without “overshooting” and selling more securities at prices below value than the bidder needs to sell.

This is demonstrated clearly in the experimental results. Despite that the bidders had the same values and the same liquidity needs in the sealed-bid auctions and in the clock auctions, the bidders attained average payoffs of 3,222 in the sealed-bid auctions and of 3,719 in the clock auctions, as shown in row 4 of Table 1. The payoffs in the clock auctions were significantly higher (at the 1% level) than in the sealed bid auction. This is entirely due to better management of liquidity with the clock auction. As shown in the third row of Table 1, the mean liquidity bonus was significantly larger, 4,517 with the clock format, compared with 3,915 with the sealed bid format. Under sealed-bid, the bidder often overshoots her liquidity need. The mean overshoot with sealed-bid was 1,984, compared with 905 for the clock format (see row 6 of Table 1). This difference is significant at the 1% level (p-value of 0.0014).

2.5 Cost of purchasing securities

There appear to be three distinct effects determining the comparison of purchase prices between the sealed-bid and dynamic auction formats. First, a dynamic auction format is generally known for mitigating the winner’s curse, leading to more aggressive bidding and to lower prices in a reverse auction. Second, as seen above, the bidders submit fewer erroneous bids in a dynamic format, leading to higher prices. Third, as seen above, a dynamic format allows bidders to manage better their liquidity needs; more than likely, this would lead to fewer

desperation offers and cause higher prices. Combining these three effects, the price comparison between sealed-bid and dynamic auction formats is ambiguous.

In the experimental results, the price difference between the two formats is not statistically significant. The bidders, with the same values and the same liquidity needs in the two auction formats produced mean clearing price points of 85.22% in the sealed-bid auctions and of 83.87% in the clock auctions (see row 1 of Table 1).

Combining the results on satisfying liquidity needs and on the cost of purchasing securities, the taxpayer would favor the descending-clock auction. While the taxpayer's expenditure is approximately equal in the sealed-bid and the clock auction, the clock auction gives "more bang for the buck"—for a given expenditure of money, the clock auction better directs resources towards satisfying the liquidity needs of the banking sector.

2.6 Variability of outcomes and informativeness of prices

Finally, there appears to be a fundamental difference in the experimental results between the sealed-bid auction and the corresponding dynamic auction. All other things being equal, the outcomes of the sealed-bid auction are more variable and random.

First, this means that the outcomes of the dynamic auction are more predictable, and thus more satisfying to risk-averse banks and regulators. The greater variability is seen in the variance of the bidder's payoff. The standard deviation of the bidder's payoff is 1,312 with the clock format compared with 1,654 with sealed-bid (see row 5 of Table 1). This difference is significant at the 1% level (p-value of 0.0095).

Second, one of the objectives of government purchases of troubled securities is to restart frozen secondary markets by providing relevant transaction prices. By doing so, the government can rely on the private market to accomplish some of the government's objectives, reducing the need for government resources. The experimental design limited the extent to which this can be seen in the data, as there were only two separate pools of securities and thus only two independent prices determined in the auctions. Nevertheless, it can be seen that the prices resulting from the dynamic auction are more accurate, an effect which can be expected to be enlarged when more independent prices are determined by an auction.

3 Conclusion

In this preliminary draft, we present our early findings from experiments conducted at the Economics Experimental Lab at the University of Maryland. The experiments demonstrate the feasibility of implementing reverse auctions for troubled assets in a short period of time using either a sealed-bid or dynamic auction format. The experiments suggest that under either format the taxpayer cost of the purchase is apt to be small (or even negative). However, the dynamic format by letting a bank better manage its liquidity needs has significant advantages for both the banks and the taxpayers.

Our experiments focused on trading profits and liquidity needs. In practice, bidders also care about portfolio risk. For reasons of simplicity, we ignore portfolio risk in the experiments. Our reasoning is that, like liquidity, portfolio risk is an aggregate requirement for the bidder. Thus, we can expect that what we learn about a bidder's challenges in managing liquidity would carry

over to the issue of portfolio risk. Including portfolio risk, then, would likely strengthen the case for dynamic auctions.

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Appendix 1

A Common-Value Auction with Liquidity Needs: Bidder Instructions for Experiment 1

12 October 2008

In this experiment, you are a bidder in a series of auctions conducted over four sessions. Each session is held on a different day and consists of four different auctions. Bidders are randomly assigned to each auction. Thus, you do not know who the other bidders are in any of your auctions. You will be bidding from your private cubical, which includes a computer and a bidder tool that is unique to you. We ask that you refrain from talking during the experiment. If you need assistance at any time, just raise your hand and one of the experimental staff will assist you.

You will be paid at the end of the experiment. Your payment is proportional to your total experimental payoff—the sum of your payoffs from each of your auctions. In particular, you will receive *$1 in take-home pay for every 10 million experimental dollars that you earn*. Throughout, dollar figures refer to your experimental payoff unless explicitly stated otherwise—and the "millions" are generally suppressed. When explicitly stated, your real dollar payment will be referred to as your *take-home payment*. We anticipate that each of you will earn a take-home payment of about $100 per experimental session on average. However, your actual take-home payment will depend on your bidding strategy, the bidding strategies of the other bidders you face, and the particular realizations of numerous random events.

In each auction, you will compete with other bidders to sell your holdings of eight securities to the Treasury. The eight different securities have different values. However, for each security, the bidders have a common value, which is unknown. Each bidder has an estimate of the common value. You profit by selling securities to the Treasury at prices above the securities' true values. You also have a need for liquidity (cash). The sale of securities to the Treasury is your source of liquidity. Thus, you care about both profits and liquidity (your sales to the Treasury).

Two formats are used:

- *Simultaneous uniform-price sealed-bid auction ("sealed-bid auction").* Bidders simultaneously submit supply curves for each of the eight securities. Supply curves are non-decreasing (i.e. upward-sloping) step functions. The auctioneer then forms the aggregate supply curve and crosses it with the Treasury's demand. The clearing price is the lowest-rejected offer. All quantity offered below the clearing price is sold at the clearing price. Quantity offered at the clearing price is rationed to balance supply and demand, using the proportionate rationing rule.
- *Simultaneous descending clock auction ("clock auction").* The securities are auctioned simultaneously. There is a price "clock" for each security indicating its tentative price per unit of quantity. Bidders express the quantities they wish to supply at the current prices. The price is decremented for each security that has excess supply, and bidders again express the quantities they wish to supply at the new prices. This process repeats until supply is made equal to demand. The tentative prices and assignments then become

final. Details of the design are presented in Ausubel and Cramton (2008), which you received earlier.

In each session, you will participate in four different auctions in the following order:

1. 4-bidder sealed-bid. A sealed bid auction with four bidders.
2. 8-bidder sealed-bid. A sealed bid auction with eight bidders.
3. 4-bidder clock. A clock auction with four bidders.
4. 8-bidder clock. A clock auction with eight bidders.

Each session, one of your two 4-bidder auctions and one of your two 8-bidder auctions will be selected at random. Your take-home payment from the session will be based on the number of (million) laboratory dollars that you earn in these two auctions only.

1 Securities

In each auction, eight securities are purchased by the Treasury. The bidders are symmetric, before the draws of bidder-specific private information about security values and liquidity needs.

In each session, two sets of bidder-specific private information are drawn independently from the same probability distributions. The first set is used in the 4-bidder auctions (auctions 1 and 3); the second set is used in the 8-bidder auctions (auctions 2 and 4). You are given no feedback following the sealed-bid auctions; thus, your behavior in the clock auctions cannot be influenced by outcomes in the sealed-bid auctions of a session.

In each 4-bidder auction, the Treasury demand is 1000 shares of each security, where each share corresponds to $1 million of face value. Each bidder has holdings of 1000 shares of each security. Thus, it is possible for a single bidder to fully satisfy the Treasury demand for a particular security; that is, for each security there may be just a single winner or there may be multiple winners. One quarter of the total available shares will be purchased by the Treasury.

In each 8-bidder auction, the Treasury demand is 2000 shares of each security, where each share corresponds to $1 million of face value. Each bidder has holdings of 500 shares. Thus, at least four bidders are required to fully satisfy the Treasury demand—there must be at least four winners. One half of the total available shares will be purchased by the Treasury.

2 Your preferences

From each auction, your payoff depends on your profits and how well your liquidity needs are met.

Common Value Auction

The value of each security in cents on the dollar is the average of eight iid random variables uniformly distributed between 0 and 100:

$$v_s = \tfrac{1}{8}\sum_{i=1}^{8} u_{is}, \text{ where } u_{is} \sim_{iid} U[0,100].$$

Suppose you are bidder i.

Your private information about security s is the realization u_{is}. Notice that both for the 8-bidder and 4-bidder auctions, the common value is the average of eight uniform draws, so that only the first four draws are revealed in the 4-bidder auction. This means that the true values have the same distribution in both 4-bidder and 8-bidder auctions and your private information has the same precision.

If you sell the quantity q_s of the security s at the price p_s, then your profit (in million $) is

$$\pi_i(p, q_i, v) = \tfrac{1}{100}\sum_{s=1}^{8}(p_s - v_s)q_{is}.$$

Liquidity need

You have a liquidity need, L_i, which is drawn iid from the uniform distribution on the interval [250, 750]. You know your own liquidity need, but not that of the other bidders. You get a bonus of $1 for every dollar of sales to the Treasury up to your liquidity need of L_i. You do *not* get any bonus for sales to the Treasury above L_i. Thus, your bonus is

$$\min\left[L_i, \tfrac{1}{100}\sum_{s=1}^{8} p_s q_{is}\right].$$

Your payoff from an auction

Combining your profit and your liquidity bonus results in your total payoff

$$U_i(p, q_i, v) = \begin{cases} \tfrac{1}{100}\sum_{s=1}^{8}(2p_s - v_s)q_{is} & \text{if } \tfrac{1}{100}\sum_{s=1}^{8} p_s q_{is} < L_i \\ L_i + \tfrac{1}{100}\sum_{s=1}^{8}(p_s - v_s)q_{is} & \text{otherwise} \end{cases}$$

Thus, an additional dollar of cash is worth two dollars when your liquidity need is not satisfied, but is worth one dollar when your liquidity need is satisfied.

3 Bidder tool and auction system

You have an Excel workbook that contains your private information for each auction. You will use the tool to submit bids in the sealed-bid auctions. In addition, the tool has features that will help your decision making in each of the auctions. Each auction has its own sheet in the tool. It is essential that you are working from the correct sheet for each auction. For example the 4-bidder sealed-bid auction is the sheet named *Sealed Bid 4*.

For the clock auctions, bidding is done via a commercial auction system customized to this setting. You use the web browser to connect to the auction system. For each clock auction, you must go to a new auction site. The URL for the auction site is given in the bidder tool on the particular auction sheet, Clock 4 or Clock 8, for the 4-bidder or 8-bidder clock auction. Once at the correct auction site, log in with the user name and password given on your auction sheet.

The auction system is easy to use. You will have an opportunity to use it in the training seminar.

An important feature of the tool is the calculation of expected security values conditional on information you specify. In a common value auction, it is important for you to condition your estimate of value on your signal *and the information winning conveys*. Since your bid is only relevant in the event that you win, you should set your bid to maximize your payoff in that event. In this way, you avoid the winner's curse, which in this case is the tendency of a naïve bidder to lose money by selling shares at prices below what they are worth. In addition, in the clock auctions, the bidder also must condition on any information revealed through the bidding process. The tool provides one flexible method of calculating an appropriate conditional expected value for each security.

4 Bidding strategy

The auction environment has three complicating features:

- *Common value auction*. You have an imperfect estimate of the good's common value.
- *Divisible good auction*. Your bid is a supply curve, specifying the quantity you wish to sell at various prices.
- *Liquidity need*. You have a specific liquidity need that is met through selling shares from your portfolio of eight securities.

The combination of these factors makes a complete equilibrium analysis impossible. Nonetheless, equilibrium analysis is possible in a simplified environment. To aid your thinking about strategy, we discuss a particular strategy, which abstracts from the complications of a divisible good auction and the liquidity needs. In particular, we assume:

1. Each bidder submits a flat supply schedule; that is, the bidder offers to sell all of her holdings of a particular security at a specified price.
2. Each bidder ignores her liquidity need, bidding as if $L_i = 0$.

With these assumptions it is possible to calculate an equilibrium strategy, which we call the *benchmark strategy*. The analysis of this strategy will be helpful in thinking about the common value feature of the auction environment.

We wish to emphasize that the benchmark strategy focuses on only one element of the auction. Your challenge is to determine your own strategy to maximize your payoff that reflects all aspects of the auction environment.

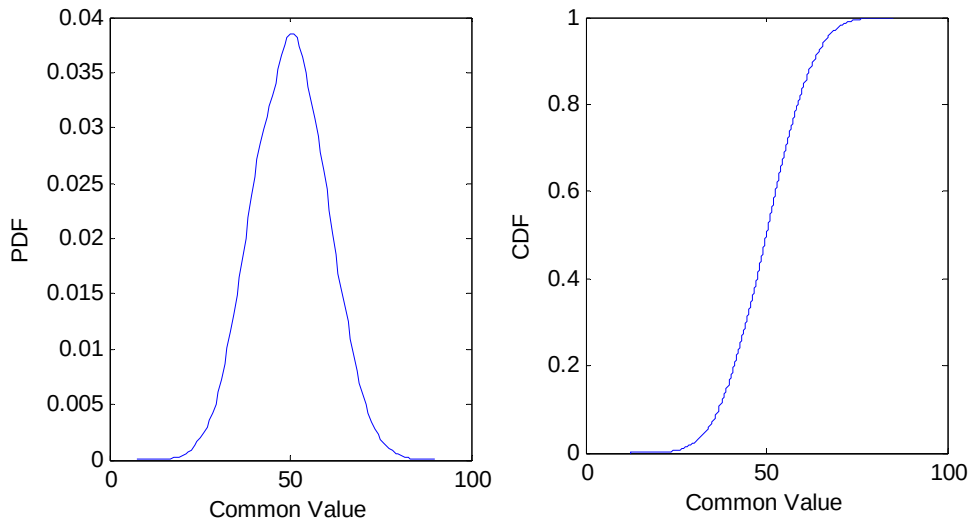
4.1 Common value distribution

As mentioned earlier, the value of each security in cents on the dollar is the average of eight iid random variables uniformly distributed between 0 and 100:

$$v_s = \tfrac{1}{8}\sum_{i=1}^{8} u_{is}, \text{ where } u_{is} \sim_{iid} U[0,100].$$

The pdf and cdf of the common value are shown in Figure 1. The common value has a mean of 50 and a standard deviation of 10.2. Notice that the common value is approximately normally distributed, since it is the sum of many independent draws.

Figure 1. Probability density and cumulative distribution of common value



You are bidder i. Your private information about security s is the realization u_{is}.

4.2 Sealed-bid uniform-price reverse auction

Under our strong simplifying assumptions, the auction is equivalent to a unit-supply common value auction with uniform pricing. In this case, just as in a single-item second-price auction, your bid does not determine what you pay, only the likelihood of winning, thus the best strategy is to bid your true conditional expected value for the good. The trick, however, is to condition on your signal and the information that winning conveys.

In the 4-bidder auction, under the benchmark assumptions, there is only a single winner, so the correct condition is as derived in Milgrom and Weber (1982). Your bid is your expected value conditional on your signal being the lowest and on the second-lowest signal being equal to yours:

$$b_{is} = E\left[v_s \mid u_1 = u_{is}, u_2 = u_1\right],$$

where u_1 is the lowest signal and u_2 is the second-lowest signal. The reason you condition on the second-lowest signal being as low as yours is that the bid must be optimal when it is on the margin and thus impacts whether you win. Your bid becomes marginal and hence decisive only in the event that you tie with the second-lowest.

For the 8-bidder auction, there are exactly four winners. Hence, we need to generalize the above formula to multiple winners. The optimal rule is to bid the expected value conditional on your signal being the fourth-lowest signal and on the fifth-lowest signal being equal to yours:

$$b_{is} = E\left[v_s \mid u_4 = u_{is}, u_5 = u_4\right],$$

where u_4 is the fourth-lowest signal and u_5 is the fifth-lowest signal.

Since the signals are uniformly distributed, it is easy to calculate the above conditional values. In both case, the conditional value is a linear function of your signal.

In the 4-bidder auction, there is a single winner. The conditioning is that you win, the next lowest bidder has your value, and the remaining two bidders are evenly distributed above your value:

$$\text{4-bidder sealed-bid strategy: } b_{is} = \frac{1}{8}\left(2u_{is} + 2\left(\frac{u_{is}+100}{2}\right) + 4\cdot 50\right) = \tfrac{3}{8}u_{is} + \tfrac{75}{2}.$$

In the 8-bidder auction, there are four winners. The conditioning is that you have the fourth-lowest signal, the fifth-lowest signal is the same, the three signals below you are evenly distributed below your signal and zero, and the remaining three bidders are evenly distributed above your signal:

$$\text{8-bidder sealed-bid strategy: } b_{is} = \frac{1}{8}\left(2u_{is} + 3\frac{u_{is}}{2} + 3\left(\frac{u_{is}+100}{2}\right)\right) = \tfrac{5}{8}u_{is} + \tfrac{75}{4}.$$

4.3 Descending clock auction

In the clock auction, under the benchmark assumption, you will observe the price at which other bidders drop out. This provides additional information on which to condition your bid. Here we assume that the price clock is continuous. In the actual experiment, the price clock is discrete, and although bidders can make reductions at any price, you will only learn the aggregate supply at the end of round price. You may want to assume the quantity reduction occurred half-way between the prior price and the ending price.

When the clock starts, you calculate your dropout point in the same way as above. As the price clock falls, one of the other bidders may drop out. When the first bidder drops out, you can calculate this bidder's draw from the following equation.

$$u_{8s} = \frac{P_{\text{dropout}} - \text{intercept}}{\text{slope}}$$

where the slope and intercept are taken the formulas above. With this new information on which to condition your bid, the revised optimal bid for the 8-bidder clock auction is straightforward to calculate.

8-bidder clock strategy

$$\text{No one has dropped out: } b_{is} = \frac{1}{8}\left(2u_{is} + 3\frac{u_{is}}{2} + 3\left(\frac{u_{is}+100}{2}\right)\right).$$

$$\text{One bidder has dropped out: } b_{is} = \frac{1}{8}\left(2u_{is} + 3\frac{u_{is}}{2} + u_8 + 2\left(\frac{u_{is}+u_8}{2}\right)\right).$$

$$\text{Two bidders have dropped out: } b_{is} = \frac{1}{8}\left(2u_{is} + 3\frac{u_{is}}{2} + u_8 + u_7 + 1\left(\frac{u_{is}+u_7}{2}\right)\right).$$

$$\text{Three bidders have dropped out: } b_{is} = \frac{1}{8}\left(2u_{is} + 3\frac{u_{is}}{2} + u_8 + u_7 + u_6\right).$$

Similarly, we can calculate the analogous formulas for the 4-bidder clock auction.

4-bidder clock strategy

$$\text{No one has dropped out: } b_{is} = \frac{1}{8}\left(2u_{is} + 2\left(\frac{u_{is} + 100}{2}\right) + 4 \cdot 50\right)$$

$$\text{One bidder has dropped out: } b_{is} = \frac{1}{8}\left(2u_{is} + u_4 + 1\left(\frac{u_{is} + u_4}{2}\right) + 4 \cdot 50\right).$$

$$\text{Two bidders have dropped out: } b_{is} = \frac{1}{8}\left(2u_{is} + u_4 + u_3 + 4 \cdot 50\right).$$

Note that the above formulas are all linear in the dropout price, so it is easy to invert to get compute the bidder's signal.

4.4 Moving beyond the benchmark strategy

The bidding tool is set up to calculate the conditional expected values assuming the benchmark strategy. Of course, you (and others) may well deviate from the benchmark strategy as a result of liquidity needs or other reasons, since these other factors are ignored in the benchmark calculation.

The bidding tool allows for this variation in a number of ways. First, in the sealed-bid auctions your bid can be any upward sloping step function to account for liquidity and possible supply reduction by you or others. Second, in the clock auctions, the tool lets you interpret what a dropout is and where it occurs. This is useful and necessary when bidders make partial reductions of supply. In addition, although the tool will calculate a particular signal based on a dropout, you are free to type in any signal inference you like. Whatever you type as "my best guess" will be used in the calculation of the conditional expected value.

Further details of the tool will be explained in the training seminar.

If you have any questions during the experiment, please raise your hand and an assistant will help you.

Remember your overall goal is to maximize your experimental payoff in each auction. You should think carefully about what strategy is best apt to achieve this goal.

Many thanks for your participation.

Appendix 2

A Common-Value Reference-Price Auction with Liquidity Needs: Bidder Instructions for Experiment 2

20 October 2008

In this experiment, you are a bidder in a series of auctions conducted over four sessions. Each session is held on a different day and consists of four different auctions. Bidders are randomly assigned to each auction. Thus, you do not know who the other bidders are in any of your auctions. You will be bidding from your private cubical, which includes a computer and a bidder tool that is unique to you. We ask that you refrain from talking during the experiment. If you need assistance at any time, just raise your hand and one of the experimental staff will assist you.

You will be paid at the end of the experiment. Your payment is proportional to your total experimental payoff—the sum of your payoffs from each of your auctions. In particular, you will receive *$1 in take-home pay for every one hundred thousand experimental dollars (100 $k) that you earn*. Throughout, dollar figures refer to your experimental payoff unless explicitly stated otherwise—and the "thousands" are generally suppressed. When explicitly stated, your real dollar payment will be referred to as your *take-home payment*. We anticipate that each of you will earn a take-home payment of about $100 per experimental session on average. However, your actual take-home payment will depend on your bidding strategy, the bidding strategies of the other bidders you face, and the particular realizations of numerous random events.

In each auction, you will compete with other bidders to sell your holdings of eight securities to the Treasury. The eight securities are split into two pools: four securities are low quality and four are high quality. The eight different securities have different values. However, for each security, the bidders have a common value, which is unknown. Each bidder has an estimate of the common value. You profit by selling securities to the Treasury at prices above the securities' true values. You also have a need for liquidity (cash). The sale of securities to the Treasury is your source of liquidity. Thus, you care about both profits and liquidity (your sales to the Treasury). The Treasury has allocated a particular budget for the purchase of each pool of securities within each auction. Its demand for high-quality securities is distinct from its demand for low-quality securities.

Before each auction, the auctioneer assigns each security a *reference price* (expressed in cents on the dollar of face value), which represents the Treasury's best estimate of what each security is worth. For example, a high-quality security might be assessed to be worth 75 cents on the dollar, while a low-quality security might be assessed to be worth 25 cents on the dollar. A *reference-price auction* determines the price-point—a percentage of the reference price—for each pool of securities. A winning bidder is paid the pool's price-point × the security's reference price for each unit of the security sold.

Two formats are used:

- *Simultaneous uniform-price sealed-bid auction ("sealed-bid auction")*. Bidders simultaneously submit supply curves for each of the eight securities. Supply curves are non-decreasing (i.e. upward-sloping) step functions, offering a quantity at each price-

point. The auctioneer then forms the aggregate supply curve and crosses it with the Treasury's demand. This is done separately for each pool (i.e., for high- and low-quality securities, separately). The clearing price-point is the lowest-rejected offer. All quantity offered at below the clearing price-point is sold at the clearing price-point times the security's reference price. Quantity offered at exactly the clearing price-point is rationed to balance supply and demand, using the proportionate rationing rule.

- *Simultaneous descending clock auction ("clock auction").* The securities are auctioned simultaneously. There are two descending clocks, one for high-quality securities and one for low-quality securities, indicating the tentative price-point of each pool. Bidders express the quantities they wish to supply at the current price-points. The price-point is decremented for each pool of securities that has excess supply, and bidders again express the quantities they wish to supply at the new price-points. This process repeats until supply is made equal to demand. The tentative price-points and assignments then become final. Details of the design are presented in Ausubel and Cramton (2008), which you received earlier.

The proportionate rationing rule only plays a role in the event that multiple bidders make reductions at the clearing price. The rule then accepts the reductions at the clearing price in proportion to the size of each bidder's reduction at the clearing price. Thus, if a reduction of 300 is needed to clear the market and two bidders made reductions of 400 and 200 at the clearing price, then the reductions are rationed proportionately: the first is reduced by 200 and the second is reduced by 100. The actual reduction of the first bidder is twice as large as the second bidder, since the first bidder's reduction as bid is twice as large as the second bidder's reduction. Ties can generally be avoided by refraining from bidding price-points that are round numbers, instead specifying price-points to odd one-hundredths of a percent (e.g., 98.42).

The clock auction has an activity rule to encourage price discovery. In particular, for each security pool, the quantities bid must be an upward-sloping supply curves as expressed in activity points. More precisely, *activity points*—equal to the reference price × quantity, summed over the four securities in the pool—are computed for each bid. The number of activity points is not permitted to increase as the price-point descends. Thus, you are allowed to switch quantities across the four securities in a pool, but your total activity points for the pool cannot increase as the auction progresses.

The same activity rule applies to the sealed-bid auction, but then in a single round of bidding.

In each session, you will participate in four different auctions:

5. Sealed-bid auction, with more precise reference prices
6. Clock auction, with more precise reference prices
7. Sealed-bid auction, with less precise reference prices
8. Clock auction, with less precise reference prices

On Tuesday and Thursday, the order of auctions will be as above. On Wednesday and Friday, the auctions with less precise reference prices will be done first.

In each session, one of your two auctions with more precise reference prices and one of your two auctions with less precise reference prices will be selected at random. Your take-home

payment from the session will be based on the number of experimental dollars that you earn in these two auctions only.

5 Securities

In each auction, the Treasury has a demand for each pool of securities: high quality and low quality. The bidders have bidder-specific private information about security values and liquidity needs.

In each session, two sets of bidder-specific private information are drawn independently from the same probability distributions. The first set is used in the auctions with more precise reference prices (auctions 1 and 2); the second set is used in the auctions with less precise reference prices (auctions 3 and 4). You are given no feedback following each sealed-bid auction; thus, your behavior in the subsequent clock auction cannot be influenced by the outcome in the prior sealed-bid auction.

The bidders differ in their security holdings as shown in Table 1.

Table 1. Holdings of securities by bidder and security in thousand $ of face value

		High-Quality Securities				Low-Quality Securities				
		H1	H2	H3	H4	L1	L2	L3	L4	Total
Bidder	1	20,000					5,000	5,000	10,000	40,000
	2		20,000			10,000		5,000	5,000	40,000
	3			20,000		5,000	10,000		5,000	40,000
	4				20,000	5,000	5,000	10,000		40,000
	5		5,000	5,000	10,000	20,000				40,000
	6	10,000		5,000	5,000		20,000			40,000
	7	5,000	10,000		5,000			20,000		40,000
	8	5,000	5,000	10,000					20,000	40,000
	Total	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	
	Expected price	75	75	75	75	25	25	25	25	
	Expected value	30,000	30,000	30,000	30,000	10,000	10,000	10,000	10,000	
	Total value	120,000				40,000				

Thus, there are four holders of each security: one large (50%), one medium (25%), and two small (12.5% each). Each bidder holds 20,000 ($k of face value) of high-quality securities and 20,000 ($k of face value) of low-quality securities.

The four high-quality securities are pooled together and sold as a pool; the four low-quality securities are pooled together and sold as a second pool. Whether done as a sealed-bid auction or done as a clock auction, the two pools are auctioned simultaneously. The Treasury has a budget of $30,000k for high-quality securities and a budget of $10,000k for low-quality securities. Thus, given the expected prices of 75 cents on the dollar for high-quality and 25 cents on the dollar for low-quality (see below), the Treasury can be expected to buy a quantity of about 40,000 ($k of face value), or 25% of face value, of each security pool. Between pools, there is no explicit interaction. However, the bidder's liquidity needs are based on sales from both pools together.

You are one of the eight bidders. You will have the same bidder number in auctions with more precise reference prices (auctions 1 and 2); you will have the same bidder number in auctions with less precise reference prices (auctions 3 and 4). Therefore, your holdings of securities and your signals will be the same in auctions 1 and 2 , and they will also be the same in

auctions 3 and 4. However, you will have different holdings of securities and signals in auctions 3 and 4, as compared with auctions 1 and 2.

6 Your preferences

From each auction, your payoff depends on your profits and how well your liquidity needs are met.

Common Value Auction

The value of each high-quality security $s \in \{H1,H2,H3,H4\}$ in cents on the dollar is the average of n iid random variables uniformly distributed between 50 and 100:

$$v_s = \tfrac{1}{n}\sum_{j=1}^{n} u_{js}, \text{ where } u_{js} \sim_{iid} U[50,100].$$

The value of each low-quality security $s \in \{L1,L2,L3,L4\}$ in cents on the dollar is the average of n iid random variables uniformly distributed between 0 and 50:

$$v_s = \tfrac{1}{n}\sum_{j=1}^{n} u_{js}, \text{ where } u_{js} \sim_{iid} U[0,50].$$

For auctions with more precise reference prices, $n = 16$; for auctions with less precise reference prices $n = 12$. The reference price r_s for security s is given by

$$r_s = \tfrac{1}{n-8}\sum_{j=9}^{n} u_{js}.$$

Thus, the reference price is based on eight realizations in the more precise case (1/2 of all realizations) and on four realizations in the less precise case (1/3 of all realizations). Reference prices are made public before each auction starts.

For each 5,000 of security holdings, bidder i receives as private information one of the realizations u_{js}. Thus, bidder 1, who holds 20,000 of security 1, gets four realizations. In this way, those with larger holdings have more precise information about the security's value. Observe that this specification requires the holders of each given security to receive collectively a total of eight realizations. Since there are eight realizations available (besides the ones that form the reference price), each of the realizations u_{js} ($i = 1, \ldots, 8$) can be observed by exactly one bidder.

Suppose that the auction clearing price-point is p_H for the high-quality pool and p_L for the low-quality pool, where the price-point in the auction is stated as a fraction of the reference price. Then $p_s = p_H\, r_s$ for $s \in \{H1,H2,H3,H4\}$ and $p_s = p_L\, r_s$ for $s \in \{L1,L2,L3,L4\}$.

If a bidder sells the quantity q_s (in thousand \$ of face value) of the security s at the price p_s, then profit (in thousand \$) is

$$\pi_i(p, q_i, v) = \tfrac{1}{100}\sum_{s}(p_s - v_s)q_{is}.$$

The 1/100 factor in the formula above and other formulas involving price is to convert cents into dollars.

Liquidity

Each bidder has a liquidity need, L_i in thousands, which is drawn iid from the uniform distribution on the interval [2500, 7500]. Each bidder knows his own liquidity need, but not that of the other bidders. The bidder receives a bonus of $1 for every dollar of sales to the Treasury up to his liquidity need:

$$\min\left[L_i, \tfrac{1}{100}\sum_s p_s q_{is}\right].$$

Payoff of bidder from an auction

Combining the profit and the liquidity penalty results in the bidder's total payoff

$$U_i(p, q_i, v) = \begin{cases} \tfrac{1}{100}\sum_s (2p_s - v_s)q_{is} & \text{if } \tfrac{1}{100}\sum_s p_s q_{is} < L_i \\ L_i + \tfrac{1}{100}\sum_s (p_s - v_s)q_{is} & \text{otherwise} \end{cases}$$

Thus, an additional dollar of cash is worth two dollars when the bidder's liquidity need is not satisfied, but is worth one dollar when the liquidity need is satisfied.

7 Bidder tool and auction system

You have an Excel workbook that contains your private information for each auction. The tool has features that will help your decision making in each of the auctions. Each auction has its own sheet in the tool. It is essential that you are working from the correct sheet for each auction. For example the sealed bid auction with more precise reference prices is the sheet named *Sealed Bid More*.

Bidding is done via a commercial auction system customized to this setting. You use the web browser to connect to the auction system. For each auction, you must go to a new auction site. The URL for the auction site is given in the bidder tool on the particular auction sheet. Once at the correct auction site, log in with the user name and password given on your auction sheet.

The auction system is easy to use. You will have an opportunity to use it in the training seminar.

An important feature of the tool is the calculation of expected security values conditional on information you specify. In a common value auction, it is important for you to condition your estimate of value on your signal *and the information winning conveys*. Since your bid is only relevant in the event that you win, you should set your bid to maximize your payoff in that event. In this way, you avoid the winner's curse, which in this case is the tendency of a naïve bidder to lose money by selling shares at prices below what they are worth. In addition, in the clock auctions, the bidder also must condition on any information revealed through the bidding process.

The bidding tool provides one flexible method of calculating an appropriate conditional expected value for each security. In particular, the tool is set up to calculate the conditional expected values for each security, given the information that you know—the reference price and your own signals—and your best guesses for the relevant other signals. Making appropriate guesses for the other signals is an important element of your strategy. Once these guesses are made, the tool will calculate the common value of the security based on your entries. In the clock

auction, you can adjust your estimates of other signals as you learn from the quantity drops of the other bidders.

The tool also lets you keep track of your liquidity bonus based on estimates that you enter for expected prices and expected quantities sold of each security.

Further details of the tool will be explained in the training seminar.

8 Bidding strategy

The auction environment has five complicating features:

- *Common value auction*. You have an imperfect estimate of each security's common value.
- *Divisible good auction*. Your bid is a supply curve, specifying the quantity you wish to sell at various price-points.
- *Demand for pool of securities*. The Treasury does not have a demand for individual securities, but for pools of securities (high- and low-quality pools).
- *Asymmetric holdings*. Bidders have different holdings of securities.
- *Liquidity need*. You have a specific liquidity need that is met through selling shares from your portfolio of eight securities.

The combination of these factors makes a complete equilibrium analysis difficult or impossible, even when we make strong simplifying assumptions. For this reason we will refrain from providing any sort of benchmark strategy.

Your challenge is to determine your own strategy to maximize your payoff that reflects all aspects of the auction environment. The best response in this auction, as in any auction is a best response to what the other bidders are actually doing.

It will be helpful to have an appreciation for the probability density of the common value in various circumstances.

Figure 1 displays the pdf of the common value for low-quality securities in the more precise case by the size of the bidder's holdings, assuming that all the known signals take on the mean value of 25. Thus, when the bidder holds 20,000 of the security there are 4 unknown signals and the standard deviation is 1.8; when the bidder holds 10,000 there are 6 unknown signals and the standard deviation is 2.2; when the bidder holds 5,000 there are 7 unknown signals and the standard deviation is 2.5.

Figure 1. Probability density of common value in more precise case by size of holdings

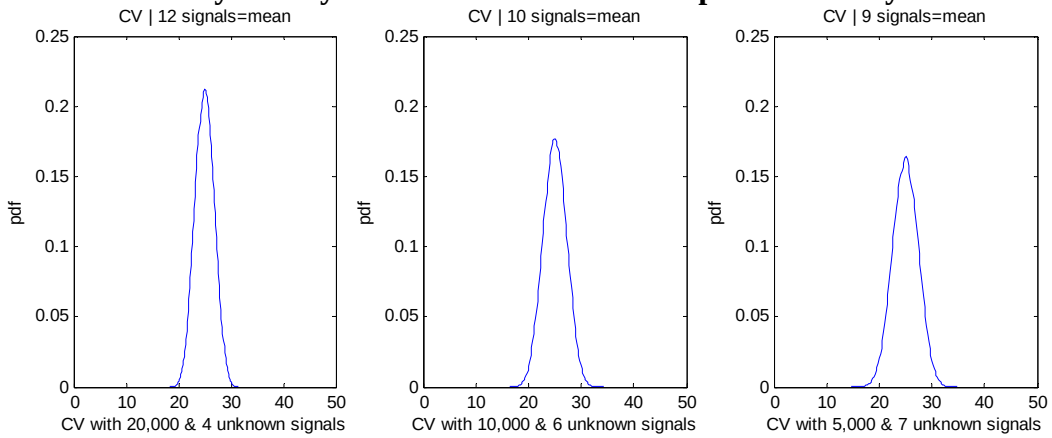
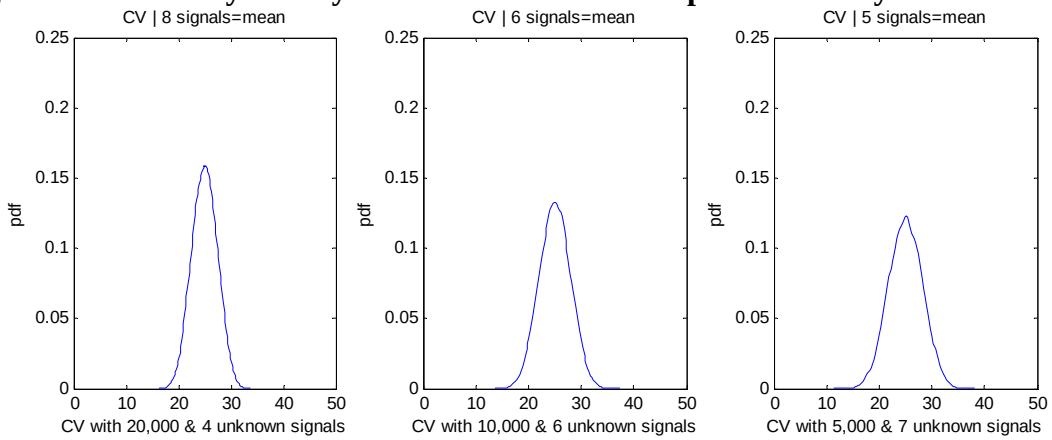


Figure 2 displays the pdf of the common value for low-quality securities in the less precise case by the size of the bidder's holdings, assuming that all the known signals take on the mean value of 25. Thus, when the bidder holds 20,000 of the security there are 4 unknown signals and the standard deviation is 2.4; when the bidder holds 10,000 there are 6 unknown signals and the standard deviation is 2.9; when the bidder holds 5,000 there are 7 unknown signals and the standard deviation is 3.2.

Figure 2. Probability density of common value in less precise case by size of holdings



If you have any questions during the experiment, please raise your hand and an assistant will help you.

Remember your overall goal is to maximize your experimental payoff in each auction. You should think carefully about what strategy is best apt to achieve this goal.

Many thanks for your participation.

Appendix 3.1

A Common-Value Auction: Bidder Instructions for Experiment 3.1

5 November 2008

In this experiment, you are a bidder in a series of auctions conducted over two sessions (Thursday, 6 November and Saturday, 8 November). Each session is held on a different day and consists of four different auctions. Bidders are randomly assigned to each auction. Thus, you do not know who the other bidders are in any of your auctions. You will be bidding from your private cubical, which includes a computer and a bidder tool that is unique to you. We ask that you refrain from talking during the experiment. If you need assistance at any time, just raise your hand and one of the experimental staff will assist you.

You will be paid at the end of the experiment. In each session, your earnings will be based on your payoff from two randomly selected auctions (out of four total auctions). Your take-home payment is then proportional to your total experimental earnings from sessions 1 and 2. In particular, you will receive *$0.40 in take-home pay for every one-million experimental dollars that you earn.* Throughout the remainder of the document, dollar figures refer to your experimental payoff unless explicitly stated otherwise—and the "millions" are generally suppressed. When explicitly stated, your real dollar payment will be referred to as your *take-home payment*. We anticipate that each of you will earn a take-home payment of about $100 per experimental session on average. However, your actual take-home payment will depend on your bidding strategy, the bidding strategies of the other bidders you face, and the particular realizations of numerous random events.

In each auction, you will compete with other bidders to sell your holdings of eight securities to the Treasury. The eight different securities have different values. However, for each security, the bidders have a common value, which is unknown. Each bidder has an estimate of the common value. You profit by selling securities to the Treasury at prices above the securities' true values. Unlike in previous experiments, you *do not* value liquidity. Thus your payoffs are based solely on profits from your sale of securities to the Treasury.

Two formats are used:

- *Simultaneous uniform-price sealed-bid auction ("sealed-bid auction").* Bidders simultaneously submit supply curves for each of the eight securities. Supply curves are non-decreasing (i.e. upward-sloping) step functions. The auctioneer then forms the aggregate supply curve and crosses it with the Treasury's demand. The clearing price is the lowest-rejected offer. All quantity offered below the clearing price is sold at the clearing price. Quantity offered at the clearing price is rationed to balance supply and demand, using the proportionate rationing rule.
- *Simultaneous descending clock auction ("clock auction").* The securities are auctioned simultaneously. There is a price "clock" for each security indicating its tentative price per unit of quantity. Bidders express the quantities they wish to supply at the current prices. The price is decremented for each security that has excess supply, and bidders again express the quantities they wish to supply at the new prices. This process repeats

until supply is made equal to demand. The tentative prices and assignments then become final. Details of the design are presented in Ausubel and Cramton (2008), which you received earlier.

The proportionate rationing rule only plays a role in the event that multiple bidders make reductions at the clearing price. The rule then accepts the reductions at the clearing price in proportion to the size of each bidder's reduction at the clearing price. Thus, if a reduction of 300 is needed to clear the market and two bidders made reductions of 400 and 200 at the clearing price, then the reductions are rationed proportionately: the first is reduced by 200 and the second is reduced by 100. The actual reduction of the first bidder is twice as large as the second bidder, since the first bidder's reduction as bid is twice as large as the second bidder's reduction. Ties can generally be avoided by refraining from bidding price-points that are round numbers, instead specifying price-points to odd one-hundredths of a percent (e.g., 98.42).

The clock auction has an activity rule to encourage price discovery. In particular, for each security, the quantities bid must be an upward-sloping supply curve. The quantity of a security is not permitted to increase as the price descends.

In each session, you will participate in *two pairs* of auctions in the following order:

9. 4-bidder sealed-bid, first pair. A sealed bid auction with four bidders.
10. 4-bidder clock, first pair. A clock auction with four bidders. The values of securities and your signals will be identical to those in the sealed-bid above.
11. 4-bidder sealed-bid, second pair. A sealed bid auction with four bidders.
12. 4-bidder clock, second pair. A clock auction with four bidders. The values of securities and your signals will be identical to those in the sealed-bid above.

Each session, one of your first pair of auctions and one of your second pair of auctions will be selected at random. Your take-home payment from the session will be based on the number of (million) laboratory dollars that you earn in these two auctions only.

9 Securities

In each auction, eight securities are purchased by the Treasury. The bidders are symmetric, before the draws of bidder-specific private information about security values.

In each session, two sets of bidder-specific private information are drawn independently from the same probability distributions. The first set is used in the first pair of auctions (auctions 1 and 2); the second set is used in the second pair of auctions (auctions 3 and 4). You are given no feedback following the sealed-bid auctions; thus, your behavior in the clock auctions cannot be influenced by outcomes in the sealed-bid auctions of a session.

In each auction, the Treasury demand is 1000 shares of each security, where each share corresponds to $1 million of face value. Each bidder has holdings of 1000 shares of each security. Thus, it is possible for a single bidder to fully satisfy the Treasury demand for a particular security; that is, for each security there may be just a single winner or there may be multiple winners. One quarter of the total available shares will be purchased by the Treasury.

10 Your preferences

From each auction, your payoff depends on your profits from the sale of securities to the Treasury.

Common Value Auction

The value of each security in cents on the dollar is the average of eight iid random variables uniformly distributed between 0 and 100:

$$v_s = \tfrac{1}{8}\sum_{i=1}^{8} u_{is}, \text{ where } u_{is} \sim_{iid} U[0,100].$$

Suppose you are bidder i.

Your private information about security s is the realization u_{is}. Notice that the common value is the average of eight uniform draws, so that only the first four draws are revealed (as there are only four bidders in the auction).

If you sell the quantity q_s of the security s at the price p_s, then your profit (in million $) is

$$\pi_i(p, q_i, v) = \tfrac{1}{100}\sum_{s=1}^{8}(p_s - v_s)q_{is}.$$

11 Bidder tool and auction system

You have an Excel workbook that contains your private information for each auction. The tool has features that will help your decision making in each of the auctions. Each auction has its own sheet in the tool. It is essential that you are working from the correct sheet for each auction. For example the sealed-bid, first-pair auction is the sheet named *Sealed Bid First Pair*.

For each of the auctions, bidding is done via a commercial auction system customized to this setting. You use the web browser to connect to the auction system. For each auction, you must go to a new auction site. The URL for the auction site is given in the bidder tool on the particular auction sheet, Sealed Bid First Pair, Clock First Pair, Sealed Bid Second Pair, or Clock Second Pair. Once at the correct auction site, log in with the user name and password given on your auction sheet.

The auction system is easy to use. It is identical to the system you used for bidding in all previous experiments.

An important feature of the tool is the calculation of expected security values conditional on information you specify. In a common value auction, it is important for you to condition your estimate of value on your signal *and the information winning conveys*. Since your bid is only relevant in the event that you win, you should set your bid to maximize your payoff in that event. In this way, you avoid the winner's curse, which in this case is the tendency of a naïve bidder to lose money by selling shares at prices below what they are worth. In addition, in the clock auctions, the bidder also must condition on any information revealed through the bidding process. The tool provides one flexible method of calculating an appropriate conditional expected value for each security.

12 Bidding strategy

The auction environment has two complicating features:

- *Common value auction*. You have an imperfect estimate of the good's common value.
- *Divisible good auction*. Your bid is a supply curve, specifying the quantity you wish to sell at various prices.

The combination of these factors makes a complete equilibrium analysis difficult. Nonetheless, equilibrium analysis is possible in a simplified environment. To aid your thinking about strategy, we discuss a particular strategy, which abstracts from the complications of a divisible good auction. In particular, we assume that each bidder submits a flat supply schedule; that is, the bidder offers to sell all of her holdings of a particular security at a specified price.

With these assumptions it is possible to calculate an equilibrium strategy, which we call the *benchmark strategy*. The analysis of this strategy will be helpful in thinking about the common value feature of the auction environment.

We wish to emphasize that the benchmark strategy focuses on only one element of the auction. Your challenge is to determine your own strategy to maximize your payoff that reflects all aspects of the auction environment.

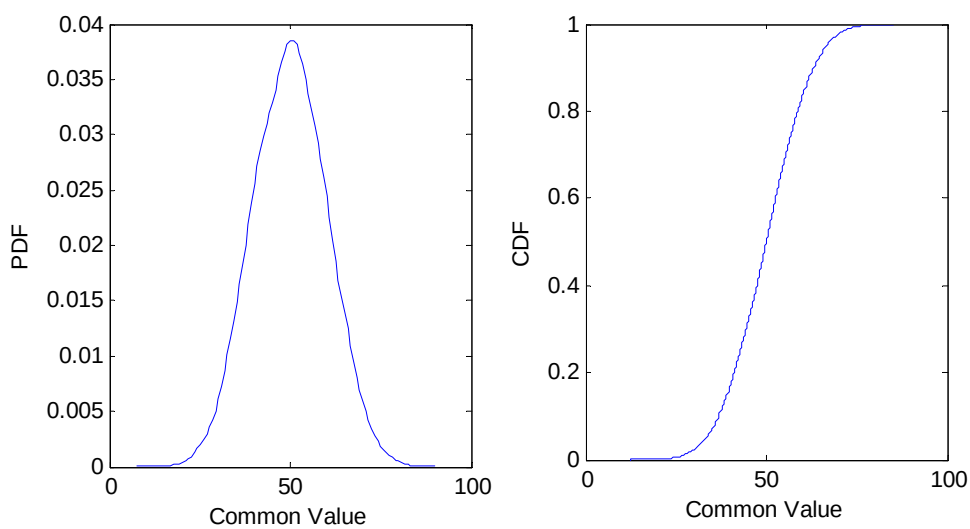
12.1 Common value distribution

As mentioned earlier, the value of each security in cents on the dollar is the average of eight iid random variables uniformly distributed between 0 and 100:

$$v_s = \tfrac{1}{8}\sum_{i=1}^{8} u_{is}, \text{ where } u_{is} \sim_{iid} U[0,100].$$

The pdf and cdf of the common value are shown in Figure 1. The common value has a mean of 50 and a standard deviation of 10.2. Notice that the common value is approximately normally distributed, since it is the sum of many independent draws.

Figure 1. Probability density and cumulative distribution of common value



You are bidder i. Your private information about security s is the realization u_{is}.

12.2 Sealed-bid uniform-price reverse auction

Under our strong simplifying assumptions, the auction is equivalent to a unit-supply common value auction with uniform pricing. In this case, just as in a single-item second-price auction, your bid does not determine what you pay, only the likelihood of winning, thus the best strategy is to bid your true conditional expected value for the good. The trick, however, is to condition on your signal and the information that winning conveys.

In the 4-bidder auction, under the benchmark assumptions, there is only a single winner, so the correct condition is as derived in Milgrom and Weber (1982). Your bid is your expected value conditional on your signal being the lowest and on the second-lowest signal being equal to yours:

$$b_{is} = E\left[v_s \mid u_1 = u_{is}, u_2 = u_1\right],$$

where u_1 is the lowest signal and u_2 is the second-lowest signal. The reason you condition on the second-lowest signal being as low as yours is that the bid must be optimal when it is on the margin and thus impacts whether you win. Your bid becomes marginal and hence decisive only in the event that you tie with the second-lowest.

Since the signals are uniformly distributed, it is easy to calculate the above conditional values. In both case, the conditional value is a linear function of your signal.

In the 4-bidder auction, there is a single winner. The conditioning is that you win, the next lowest bidder has your value, and the remaining two bidders are evenly distributed above your value:

$$\text{4-bidder sealed-bid strategy: } b_{is} = \frac{1}{8}\left(2u_{is} + 2\left(\frac{u_{is} + 100}{2}\right) + 4 \cdot 50\right) = \tfrac{3}{8}u_{is} + \tfrac{75}{2}.$$

12.3 Descending clock auction

In the clock auction, under the benchmark assumption, you will observe the price at which other bidders drop out. This provides additional information on which to condition your bid. Here we assume that the price clock is continuous. In the actual experiment, the price clock is discrete, and although bidders can make reductions at any price, you will only learn the aggregate supply at the end of round price. You may want to assume the quantity reduction occurred half-way between the prior price and the ending price.

When the clock starts, you calculate your dropout point in the same way as above. As the price clock falls, one of the other bidders may drop out. When the first bidder drops out, you can calculate this bidder's draw from the following equation.

$$u_{8s} = \frac{P_{\text{dropout}} - \text{intercept}}{\text{slope}}$$

where the slope and intercept are taken the formulas above. With this new information on which to condition your bid, the revised optimal bid for the 4-bidder clock auction is straightforward to calculate.

4-bidder clock strategy

$$\text{No one has dropped out: } b_{is} = \frac{1}{8}\left(2u_{is} + 2\left(\frac{u_{is} + 100}{2}\right) + 4 \cdot 50\right)$$

$$\text{One bidder has dropped out: } b_{is} = \frac{1}{8}\left(2u_{is} + u_4 + 1\left(\frac{u_{is} + u_4}{2}\right) + 4 \cdot 50\right).$$

$$\text{Two bidders have dropped out: } b_{is} = \frac{1}{8}\left(2u_{is} + u_4 + u_3 + 4 \cdot 50\right).$$

Note that the above formulas are all linear in the dropout price, so it is easy to invert to get compute the bidder's signal.

12.4 Moving beyond the benchmark strategy

The bidding tool is set up to calculate the conditional expected values assuming the benchmark strategy. Of course, you (and others) may well deviate from the benchmark strategy.

The bidding tool allows for this variation in a number of ways. First, in the sealed-bid auctions your bid can be any upward sloping step function to account for possible supply reduction by you or others. Second, in the clock auctions, the tool lets you interpret what a dropout is and where it occurs. This is useful and necessary when bidders make partial reductions of supply. In addition, although the tool will calculate a particular signal based on a dropout, you are free to type in any signal inference you like. Whatever you type as "my best guess" will be used in the calculation of the conditional expected value.

If you have any questions during the experiment, please raise your hand and an assistant will help you.

Remember your overall goal is to maximize your experimental payoff in each auction. You should think carefully about what strategy is best apt to achieve this goal.

Many thanks for your participation.

Appendix 3.2

A Common-Value Reference-Price Auction: Bidder Instructions for Experiment 3.2

8 November 2008

In this experiment, you are a bidder in a series of auctions conducted over two sessions (Monday, 10 November and Tuesday, 11 November). Each session is held on a different day and consists of four different auctions. Bidders are randomly assigned to each auction. Thus, you do not know who the other bidders are in any of your auctions. You will be bidding from your private cubical, which includes a computer and a bidder tool that is unique to you. We ask that you refrain from talking during the experiment. If you need assistance at any time, just raise your hand and one of the experimental staff will assist you.

You will be paid at the end of the experiment. In each session, your earnings will be based on your payoff from two randomly selected auctions (out of four total auctions). Your take-home payment is then proportional to your total experimental earnings from sessions 1 and 2. In particular, you will receive *$0.30 in take-home pay for every one thousand experimental dollars ($k) that you earn*. Throughout, dollar figures refer to your experimental payoff unless explicitly stated otherwise—and the "thousands" are generally suppressed. When explicitly stated, your real dollar payment will be referred to as your *take-home payment*. We anticipate that each of you will earn a take-home payment of about $100 per experimental session on average. However, your actual take-home payment will depend on your bidding strategy, the bidding strategies of the other bidders you face, and the particular realizations of numerous random events.

In each auction, you will compete with other bidders to sell your holdings of eight securities to the Treasury. The eight securities are split into two pools: four securities are low quality and four are high quality. The eight different securities have different values. However, for each security, the bidders have a common value, which is unknown. Each bidder has an estimate of the common value. You profit by selling securities to the Treasury at prices above the securities' true values. The Treasury has allocated a particular budget for the purchase of each pool of securities within each auction. Its demand for high-quality securities is distinct from its demand for low-quality securities.

Before each auction, the auctioneer assigns each security a *reference price* (expressed in cents on the dollar of face value), which represents the Treasury's best estimate of what each security is worth. For example, a high-quality security might be assessed to be worth 75 cents on the dollar, while a low-quality security might be assessed to be worth 25 cents on the dollar. A *reference-price auction* determines the price-point—a percentage of the reference price—for each pool of securities. A winning bidder is paid the pool's price-point × the security's reference price for each unit of the security sold.

Two formats are used:

- *Simultaneous uniform-price sealed-bid auction ("sealed-bid auction")*. Bidders simultaneously submit supply curves for each of the eight securities. Supply curves are non-decreasing (i.e. upward-sloping) step functions, offering a quantity at each price-point. The auctioneer then forms the aggregate supply curve and crosses it with the

Treasury's demand. This is done separately for each pool (i.e., for high- and low-quality securities, separately). The clearing price-point is the lowest-rejected offer. All quantity offered at below the clearing price-point is sold at the clearing price-point times the security's reference price. Quantity offered at exactly the clearing price-point is rationed to balance supply and demand, using the proportionate rationing rule.

- *Simultaneous descending clock auction ("clock auction").* The securities are auctioned simultaneously. There are two descending clocks, one for high-quality securities and one for low-quality securities, indicating the tentative price-point of each pool. Bidders express the quantities they wish to supply at the current price-points. The price-point is decremented for each pool of securities that has excess supply, and bidders again express the quantities they wish to supply at the new price-points. This process repeats until supply is made equal to demand. The tentative price-points and assignments then become final. Details of the design are presented in Ausubel and Cramton (2008), which you received earlier.

The proportionate rationing rule only plays a role in the event that multiple bidders make reductions at the clearing price. The rule then accepts the reductions at the clearing price in proportion to the size of each bidder's reduction at the clearing price. Thus, if a reduction of 300 is needed to clear the market and two bidders made reductions of 400 and 200 at the clearing price, then the reductions are rationed proportionately: the first is reduced by 200 and the second is reduced by 100. The actual reduction of the first bidder is twice as large as the second bidder, since the first bidder's reduction as bid is twice as large as the second bidder's reduction. Ties can generally be avoided by refraining from bidding price-points that are round numbers, instead specifying price-points to odd one-hundredths of a percent (e.g., 98.42).

The clock auction has an activity rule to encourage price discovery. In particular, for each security pool, the quantities bid must be an upward-sloping supply curves as expressed in activity points. More precisely, *activity points*—equal to the reference price × quantity, summed over the four securities in the pool—are computed for each bid. The number of activity points is not permitted to increase as the price-point descends. Thus, you are allowed to switch quantities across the four securities in a pool, but your total activity points for the pool cannot increase as the auction progresses.

The same activity rule applies to the sealed-bid auction, but then in a single round of bidding.

In each session, you will participate in *two pairs* of auctions in the following order:

13. Sealed-bid auction, first pair.
14. Clock auction, first pair.
15. Sealed-bid auction, second pair.
16. Clock auction, second pair.

In all cases, the reference prices will be based on 4 signals. That is, the reference prices will be analogous to those used in the *less precise* auctions from experiment 2.

Each session, one of your first pair of auctions and one of your second pair of auctions will be selected at random. Your take-home payment from the session will be based on the number of (million) laboratory dollars that you earn in these two auctions only.

13 Securities

In each auction, the Treasury has a demand for each pool of securities: high quality and low quality. The bidders have bidder-specific private information about security values.

In each session, two sets of bidder-specific private information are drawn independently from the same probability distributions. The first set is used in the first pair of auctions (auctions 1 and 2); the second set is used in the second pair of auctions (auctions 3 and 4). You are given no feedback following each sealed-bid auction; thus, your behavior in the subsequent clock auction cannot be influenced by the outcome in the prior sealed-bid auction.

The bidders differ in their security holdings as shown in Table 1.

Table 1. Holdings of securities by bidder and security in thousand $ of face value

		High-Quality Securities				Low-Quality Securities				
		H1	H2	H3	H4	L1	L2	L3	L4	Total
Bidder	1	20,000					5,000	5,000	10,000	40,000
	2		20,000			10,000		5,000	5,000	40,000
	3			20,000		5,000	10,000		5,000	40,000
	4				20,000	5,000	5,000	10,000		40,000
	5		5,000	5,000	10,000	20,000				40,000
	6	10,000		5,000	5,000		20,000			40,000
	7	5,000	10,000		5,000			20,000		40,000
	8	5,000	5,000	10,000					20,000	40,000
	Total	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	
	Expected price	75	75	75	75	25	25	25	25	
	Expected value	30,000	30,000	30,000	30,000	10,000	10,000	10,000	10,000	
	Total value	120,000				40,000				

Thus, there are four holders of each security: one large (50%), one medium (25%), and two small (12.5% each). Each bidder holds 20,000 ($k of face value) of high-quality securities and 20,000 ($k of face value) of low-quality securities.

The four high-quality securities are pooled together and sold as a pool; the four low-quality securities are pooled together and sold as a second pool. Whether done as a sealed-bid auction or done as a clock auction, the two pools are auctioned simultaneously. The Treasury has a budget of $30,000k for high-quality securities and a budget of $10,000k for low-quality securities. Thus, given the expected prices of 75 cents on the dollar for high-quality and 25 cents on the dollar for low-quality (see below), the Treasury can be expected to buy a quantity of about 40,000 ($k of face value), or 25% of face value, of each security pool. Between pools, there is no explicit interaction.

You are one of the eight bidders. You will have the same bidder number in the first pair of auctions (auctions 1 and 2); you will have the same bidder number in the second pair of auctions (auctions 3 and 4). Therefore, your holdings of securities and your signals will be the same in auctions 1 and 2 , and they will also be the same in auctions 3 and 4. However, you will have different holdings of securities and signals in auctions 3 and 4, as compared with auctions 1 and 2.

14 Your preferences

From each auction, your payoff depends on your profits.

Common Value Auction

The value of each high-quality security $s \in \{H1,H2,H3,H4\}$ in cents on the dollar is the average of 12 iid random variables uniformly distributed between 50 and 100:

$$v_s = \tfrac{1}{12}\sum_{j=1}^{12} u_{js}, \text{ where } u_{js} \sim_{iid} U[50,100].$$

The value of each low-quality security $s \in \{L1,L2,L3,L4\}$ in cents on the dollar is the average of 12 iid random variables uniformly distributed between 0 and 50:

$$v_s = \tfrac{1}{12}\sum_{j=1}^{12} u_{js}, \text{ where } u_{js} \sim_{iid} U[0,50].$$

The reference price r_s for security s is given by

$$r_s = \tfrac{1}{4}\sum_{j=9}^{12} u_{js}.$$

Thus, the reference price is based on four realizations (1/3 of all realizations). Reference prices are made public before each auction starts.

For each 5,000 of security holdings, bidder i receives as private information one of the realizations u_{js}. Thus, bidder 1, who holds 20,000 of security 1, gets four realizations. In this way, those with larger holdings have more precise information about the security's value. Observe that this specification requires the holders of each given security to receive collectively a total of eight realizations. Since there are eight realizations available (besides the ones that form the reference price), each of the realizations u_{js} (i = 1, …, 8) can be observed by exactly one bidder.

Suppose that the auction clearing price-point is p_H for the high-quality pool and p_L for the low-quality pool, where the price-point in the auction is stated as a fraction of the reference price. Then $p_s = p_H\, r_s$ for $s \in \{H1,H2,H3,H4\}$ and $p_s = p_L\, r_s$ for $s \in \{L1,L2,L3,L4\}$.

If a bidder sells the quantity q_s (in thousand \$ of face value) of the security s at the price p_s, then profit (in thousand \$) is

$$\pi_i(p, q_i, v) = \tfrac{1}{100}\sum_s (p_s - v_s) q_{is}.$$

The 1/100 factor in the formula above and other formulas involving price is to convert cents into dollars.

15 Bidder tool and auction system

You have an Excel workbook that contains your private information for each auction. The tool has features that will help your decision making in each of the auctions. Each auction has its own sheet in the tool. It is essential that you are working from the correct sheet for each auction. For example the sealed bid auction from the first pair is the sheet named *Sealed Bid First Pair*.

Bidding is done via a commercial auction system customized to this setting. You use the web browser to connect to the auction system. For each auction, you must go to a new auction

site. The URL for the auction site is given in the bidder tool on the particular auction sheet. Once at the correct auction site, log in with the user name and password given on your auction sheet.

The auction system is easy to use. It is identical to the system you used for bidding in all previous experiments.

An important feature of the tool is the calculation of expected security values conditional on information you specify. In a common value auction, it is important for you to condition your estimate of value on your signal *and the information winning conveys*. Since your bid is only relevant in the event that you win, you should set your bid to maximize your payoff in that event. In this way, you avoid the winner's curse, which in this case is the tendency of a naïve bidder to lose money by selling shares at prices below what they are worth. In addition, in the clock auctions, the bidder also must condition on any information revealed through the bidding process.

The bidding tool provides one flexible method of calculating an appropriate conditional expected value for each security. In particular, the tool is set up to calculate the conditional expected values for each security, given the information that you know—the reference price and your own signals—and your best guesses for the relevant other signals. Making appropriate guesses for the other signals is an important element of your strategy. Once these guesses are made, the tool will calculate the common value of the security based on your entries. In the clock auction, you can adjust your estimates of other signals as you learn from the quantity drops of the other bidders.

16 Bidding strategy

The auction environment has four complicating features:

- *Common value auction*. You have an imperfect estimate of each security's common value.
- *Divisible good auction*. Your bid is a supply curve, specifying the quantity you wish to sell at various price-points.
- *Demand for pool of securities*. The Treasury does not have a demand for individual securities, but for pools of securities (high- and low-quality pools).
- *Asymmetric holdings*. Bidders have different holdings of securities.

The combination of these factors makes a complete equilibrium analysis difficult or impossible, even when we make strong simplifying assumptions. For this reason we will refrain from providing any sort of benchmark strategy.

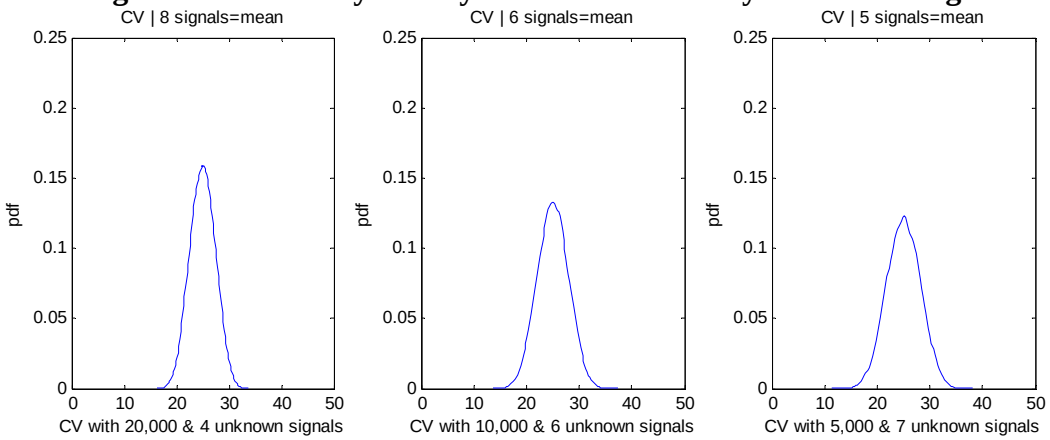
Your challenge is to determine your own strategy to maximize your payoff that reflects all aspects of the auction environment. The best response in this auction, as in any auction is a best response to what the other bidders are actually doing.

It will be helpful to have an appreciation for the probability density of the common value in various circumstances.

Figure 1 displays the pdf of the common value for low-quality securities by the size of the bidder's holdings, assuming that all the known signals take on the mean value of 25. Thus, when the bidder holds 20,000 of the security there are 4 unknown signals and the standard deviation is

2.4; when the bidder holds 10,000 there are 6 unknown signals and the standard deviation is 2.9; when the bidder holds 5,000 there are 7 unknown signals and the standard deviation is 3.2.

Figure 1. Probability density of common value by size of holdings



If you have any questions during the experiment, please raise your hand and an assistant will help you.

Remember your overall goal is to maximize your experimental payoff in each auction. You should think carefully about what strategy is best apt to achieve this goal.

Many thanks for your participation.

Appendix 4

Figures from Experiment 1: Security-by-Security Auctions

Figure A4.1. Price minus true value by day and case

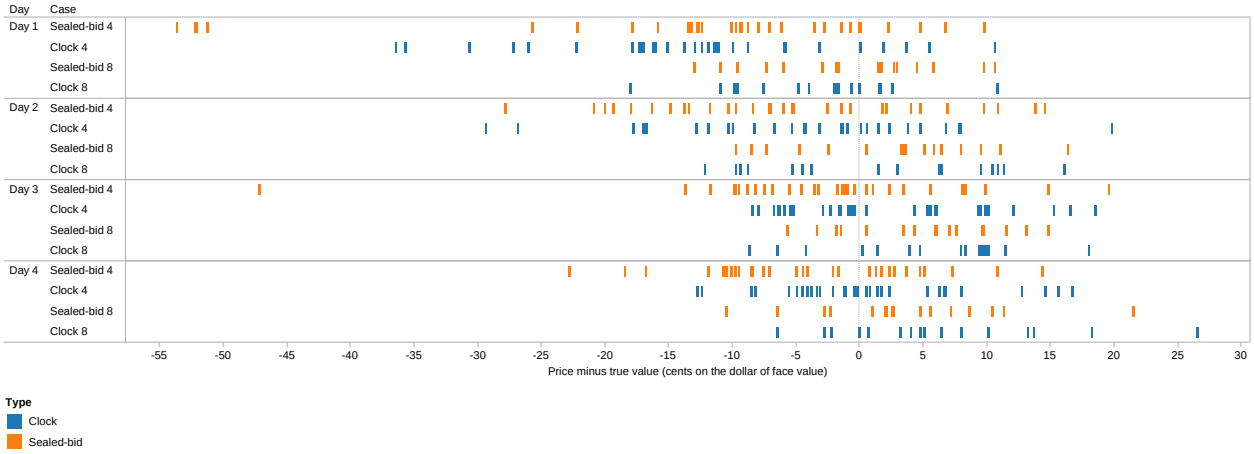


Figure A4.2. Average price minus true value by day and case

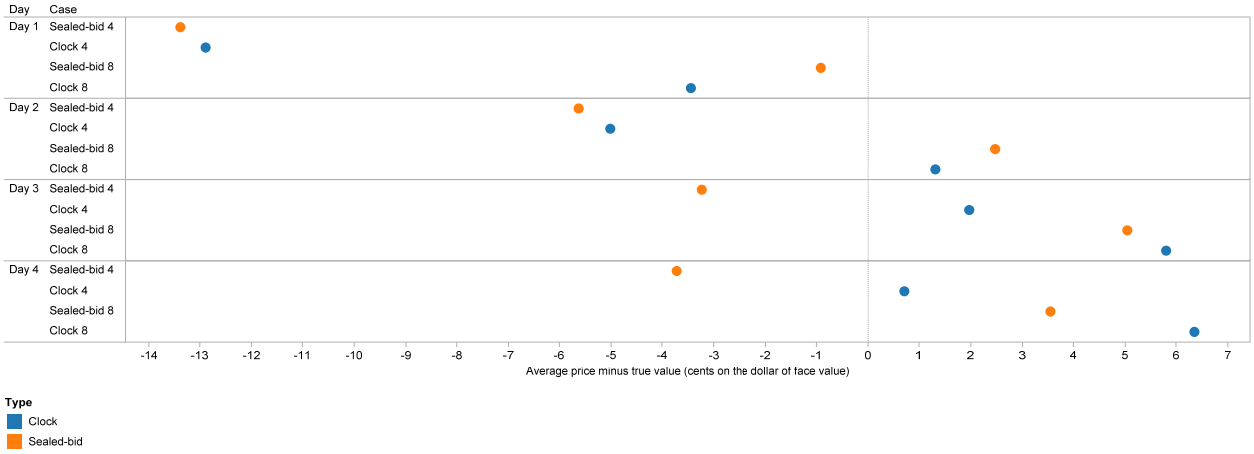


Figure A4.3. Average price minus true value by case

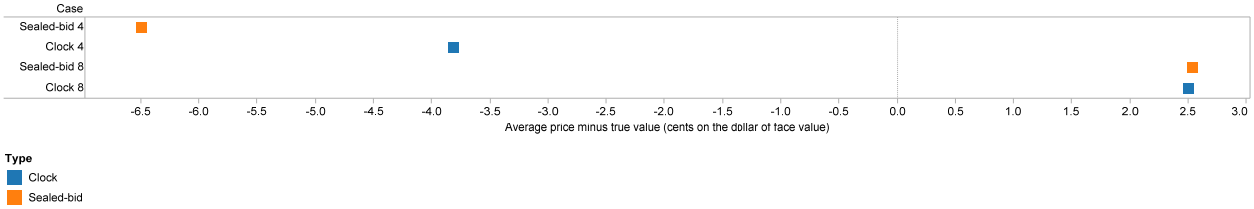


Figure A4.4. Profit by day and case

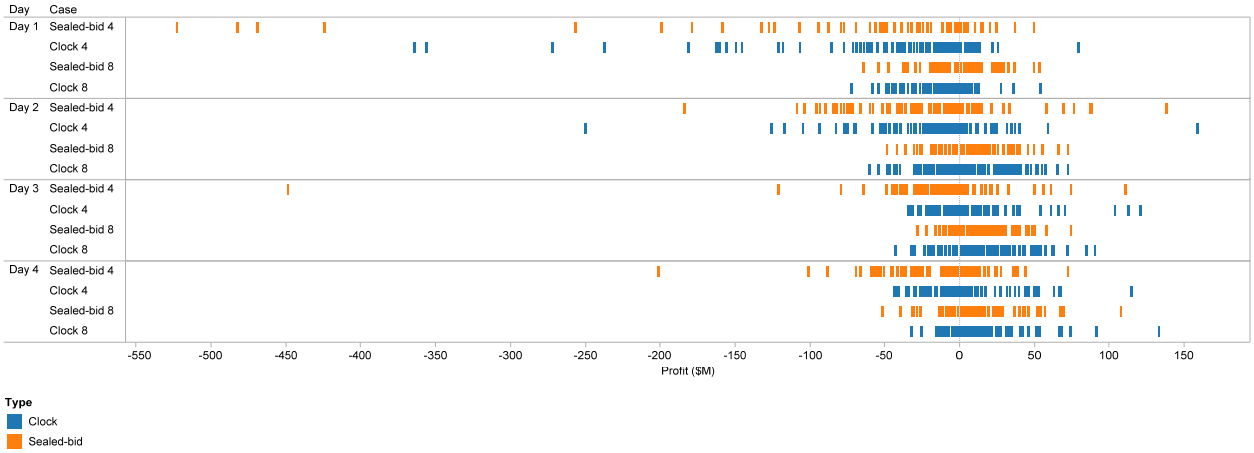


Figure A4.5. Total profit by day and case

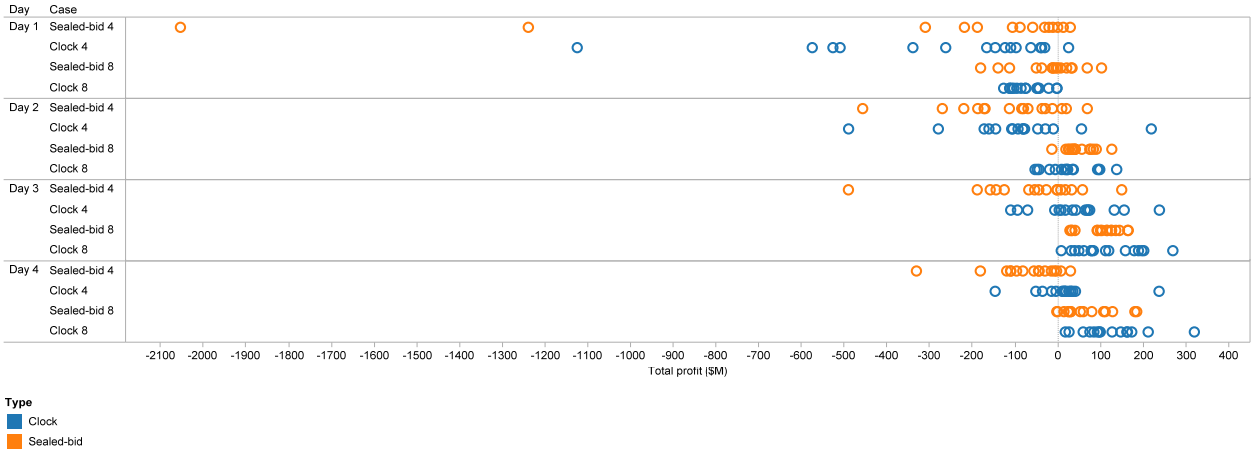


Figure A4.6. Average total profit by case

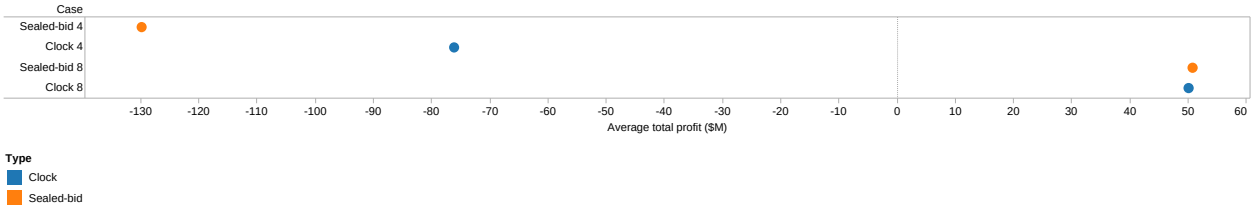


Figure A4.7. Liquidity bonus by day and case

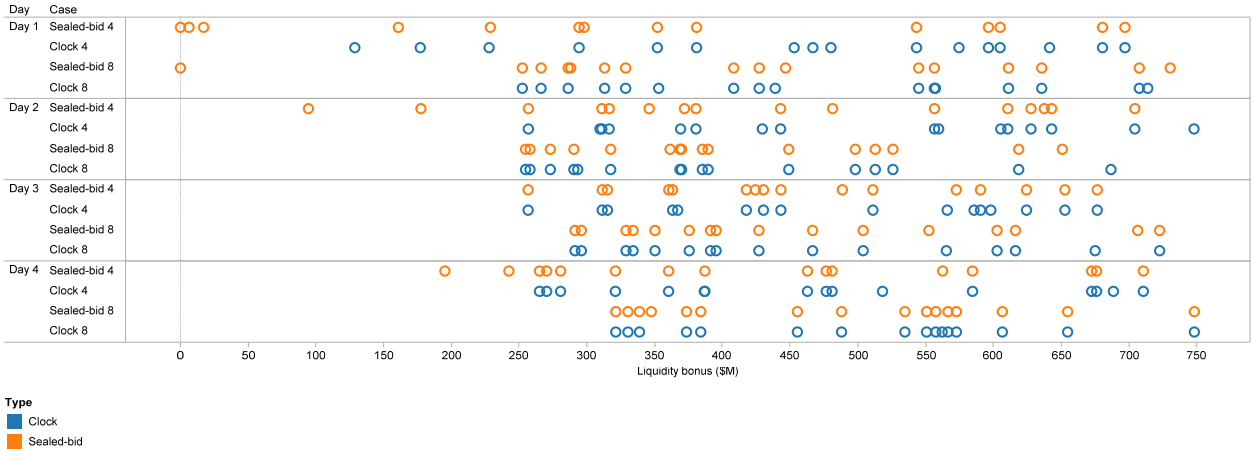


Figure A4.8. Average liquidity bonus by case

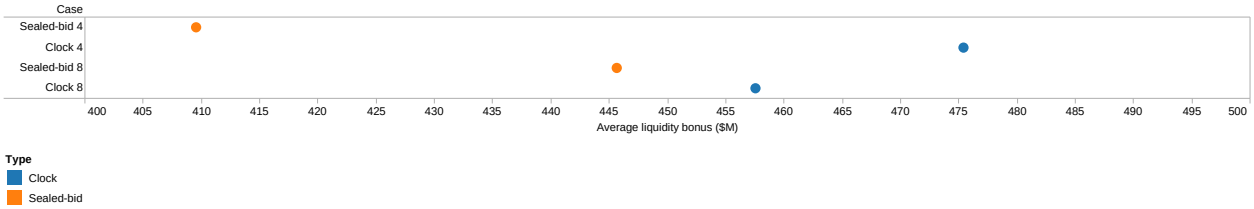


Figure A4.9. Payoff by day and case

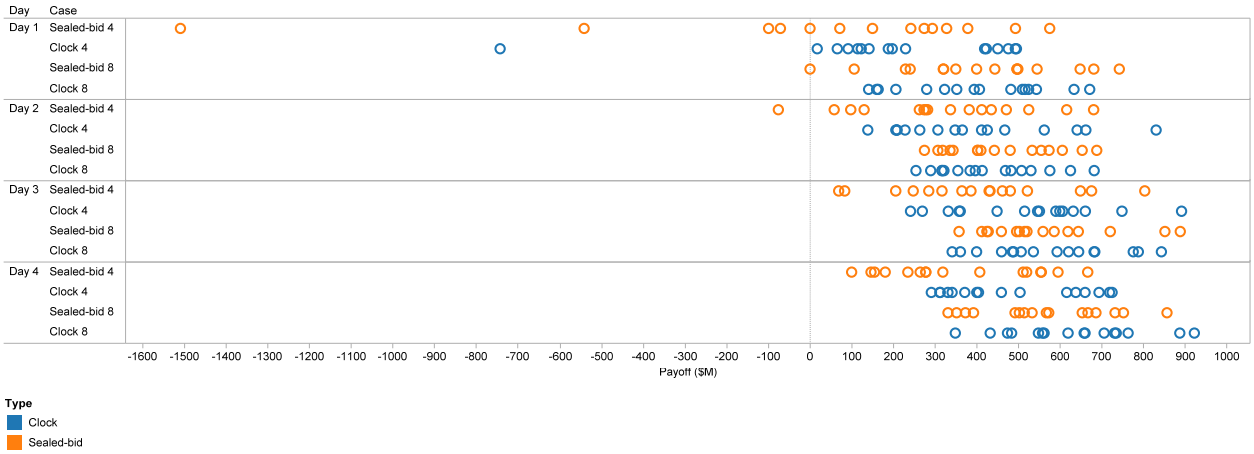


Figure A4.10. Average payoff by case

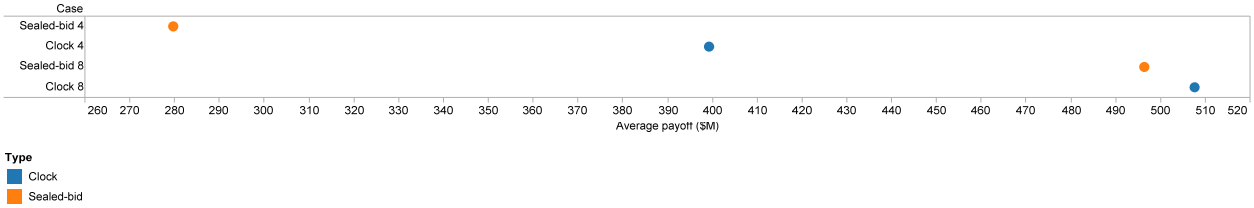


Figure A4.11. Standard deviation of price minus true value across bidders by day and case

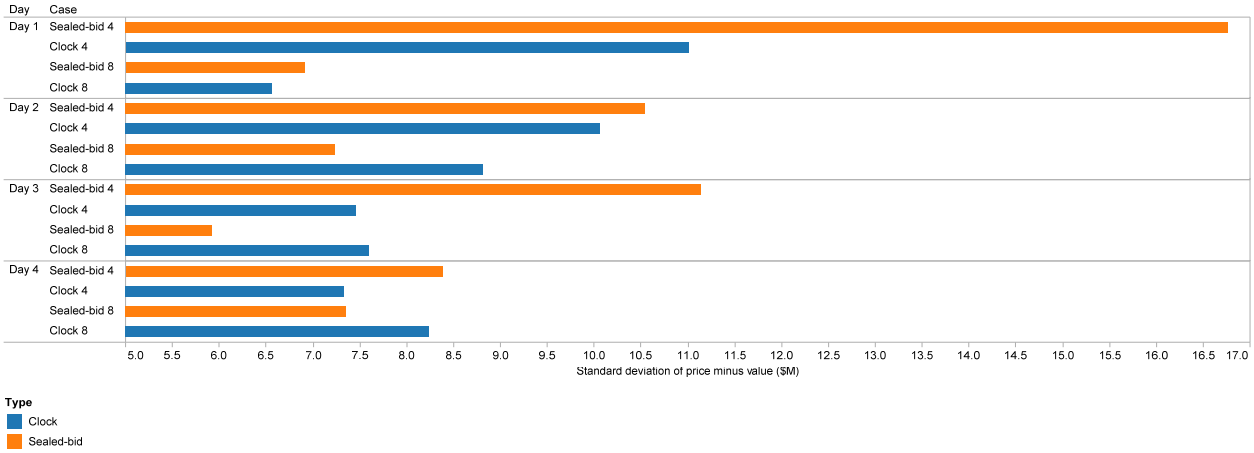


Figure A4.12. Standard deviation of price minus true value across bidders and day by case

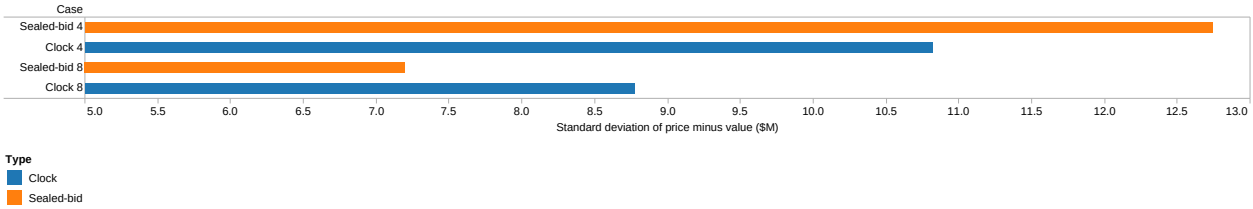


Figure A4.13. Standard deviation of profit across bidders by day and case

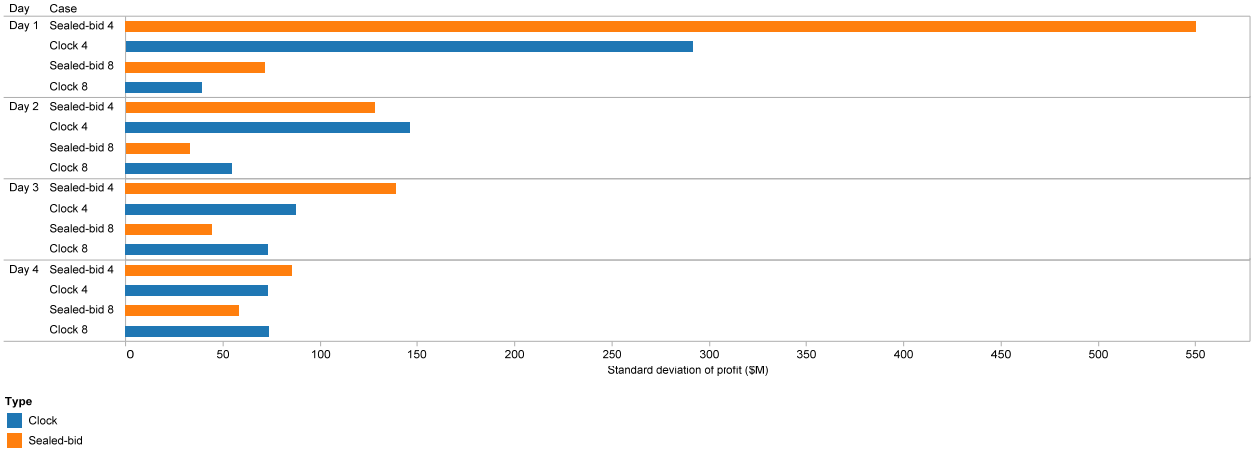


Figure A4.14. Standard deviation of profit across bidders and day by case

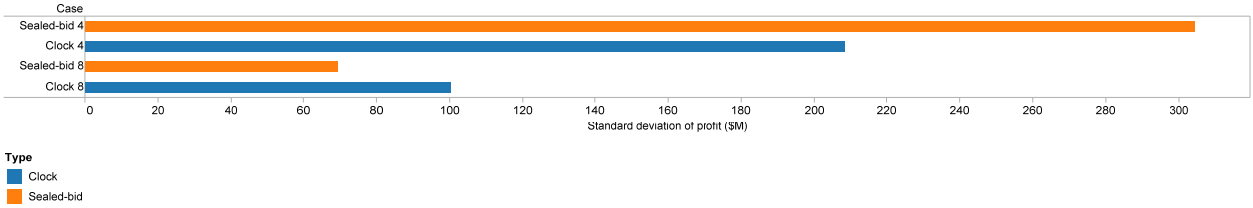


Figure A4.15. Standard deviation of liquidity bonus across bidders by day and case

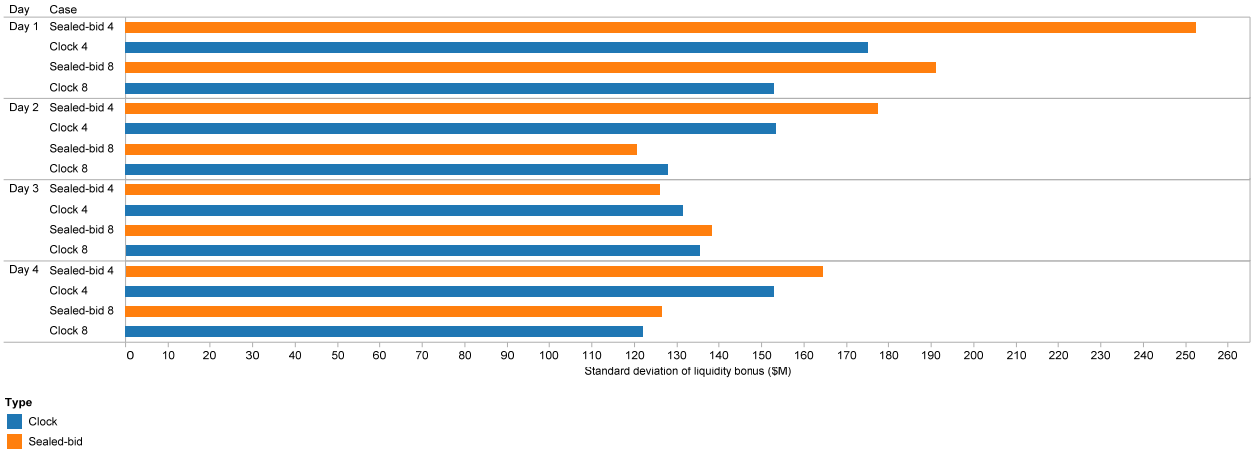


Figure A4.16. Standard deviation of liquidity bonus across bidders and day by case

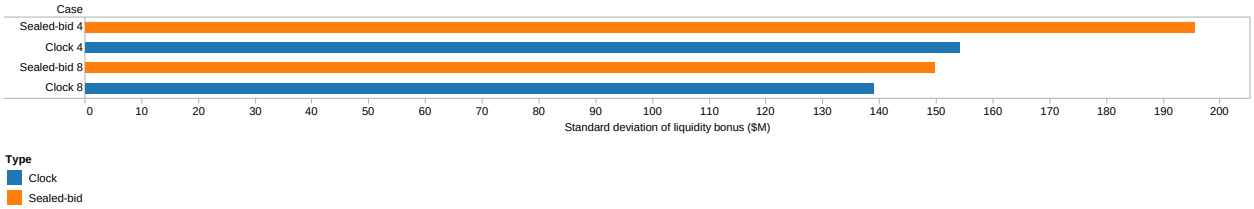


Figure A4.17. Standard deviation of payoff across bidders by day and case

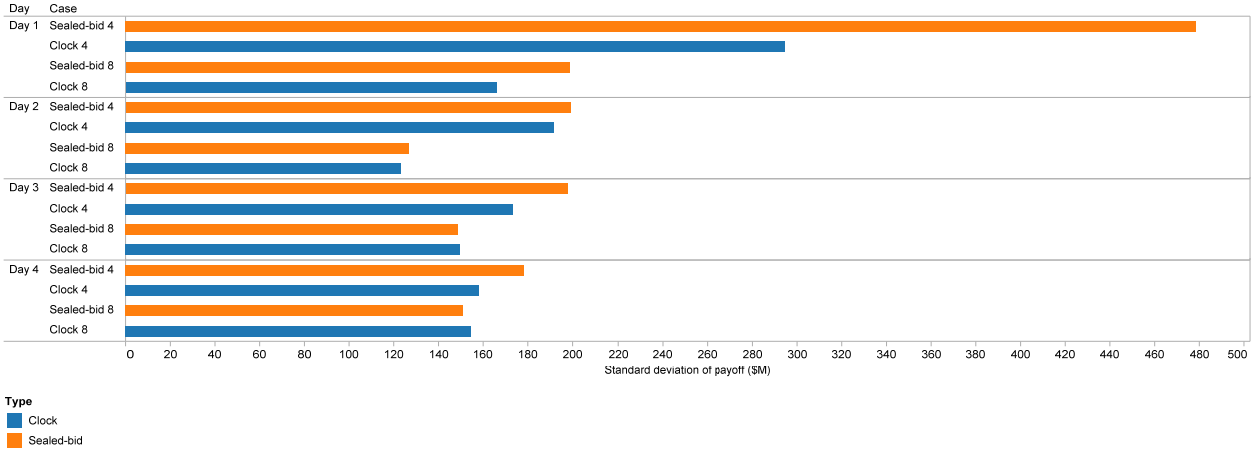


Figure A4.18. Standard deviation of payoff across bidders and day by case

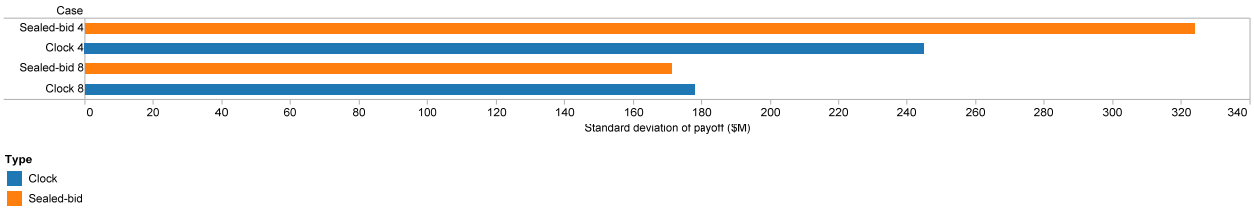


Figure A4.19. Supply and demand by number of bidders (day 1, auction a)

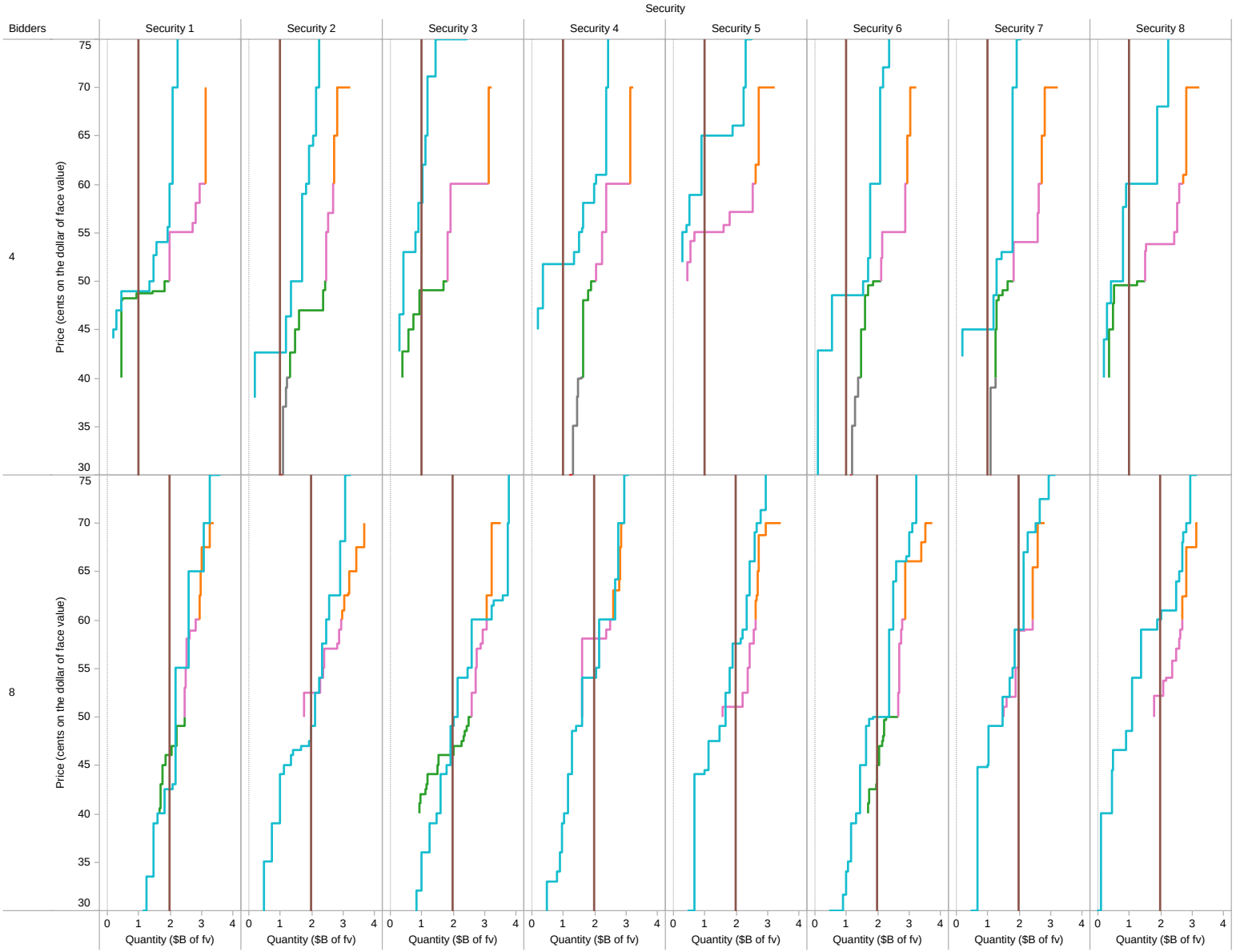


Figure A4.20. Supply and demand by number of bidders (day 1, auction b)

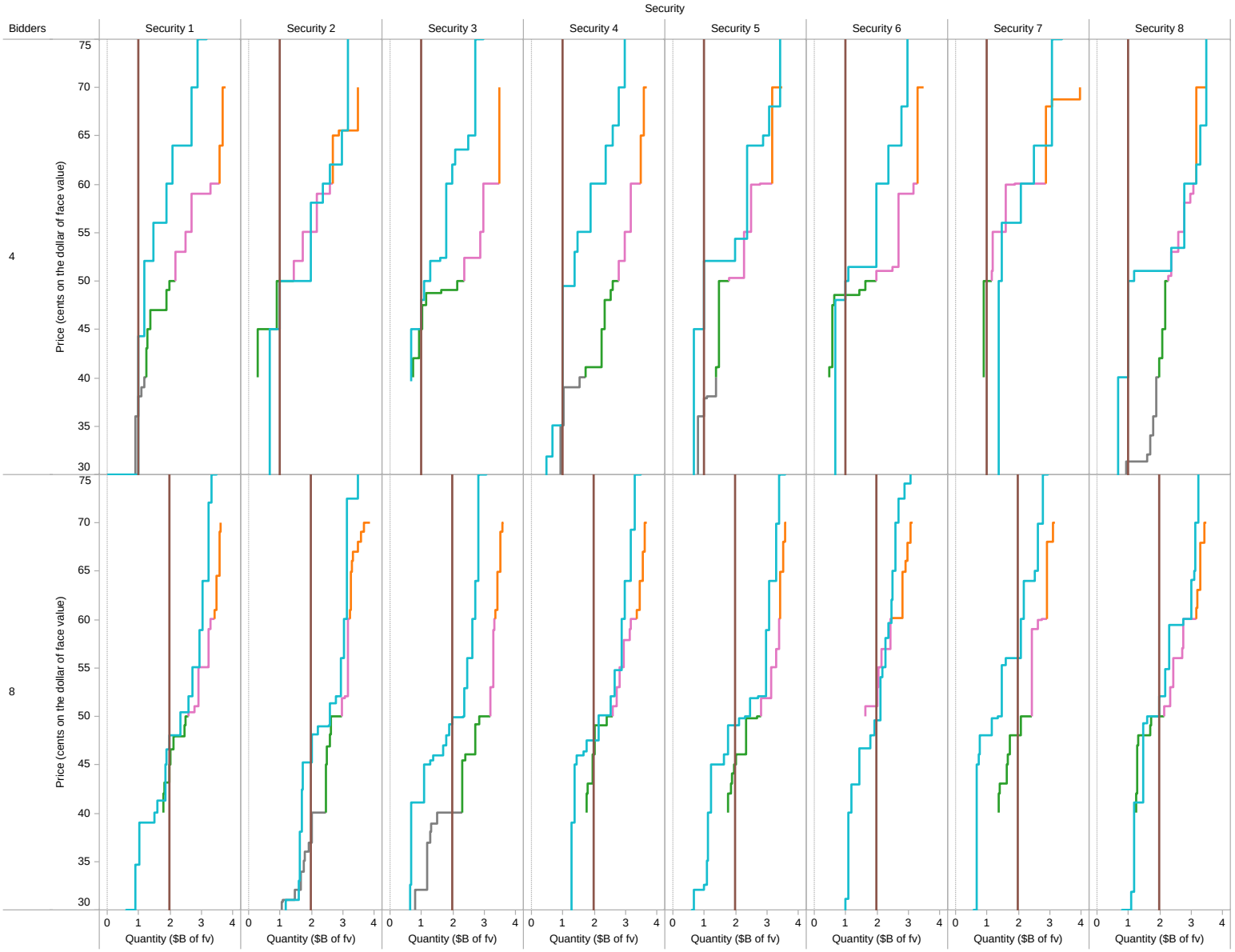


Figure A4.21. Supply and demand by number of bidders (day 1, auction c)

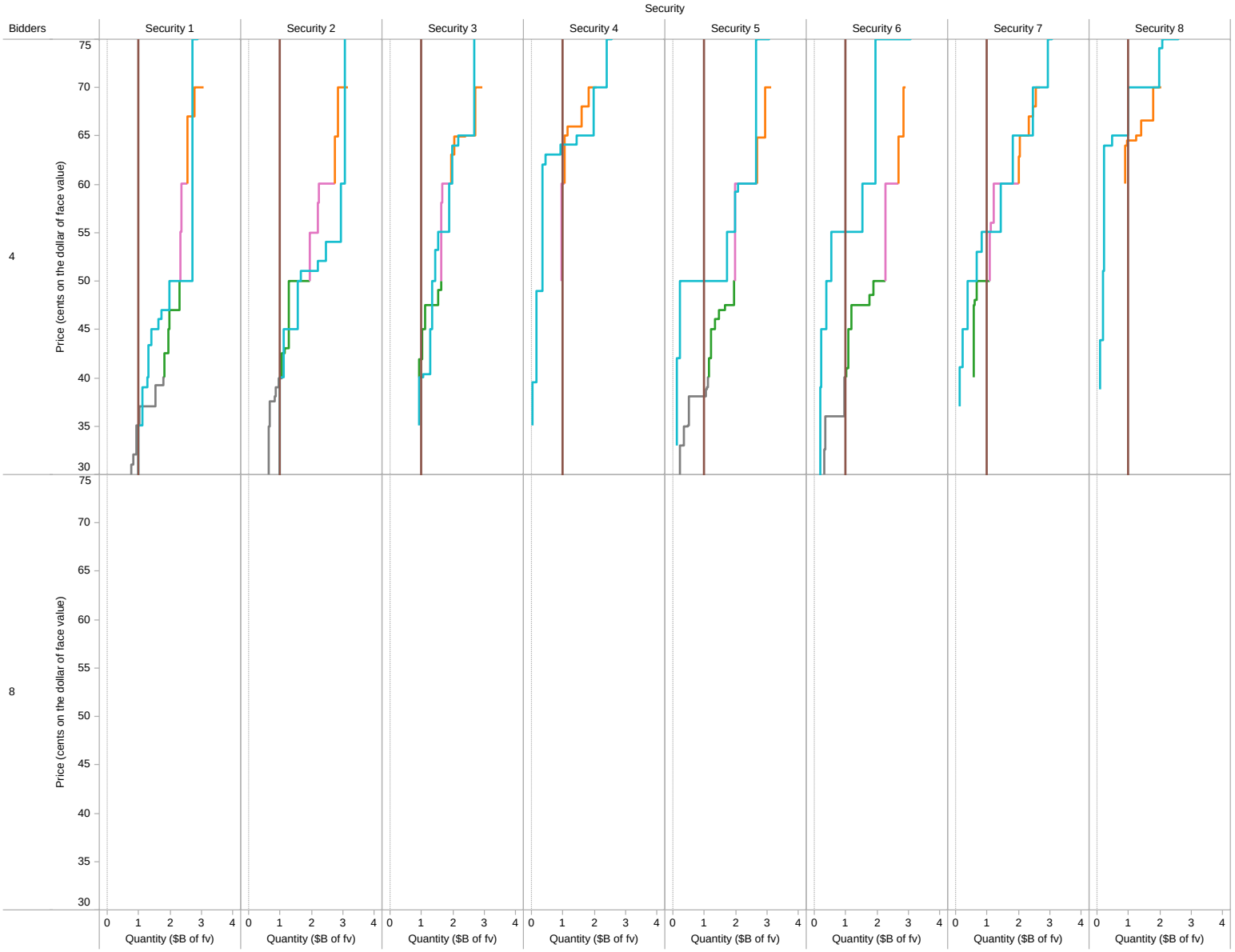


Figure A4.22. Supply and demand by number of bidders (day 1, auction d)

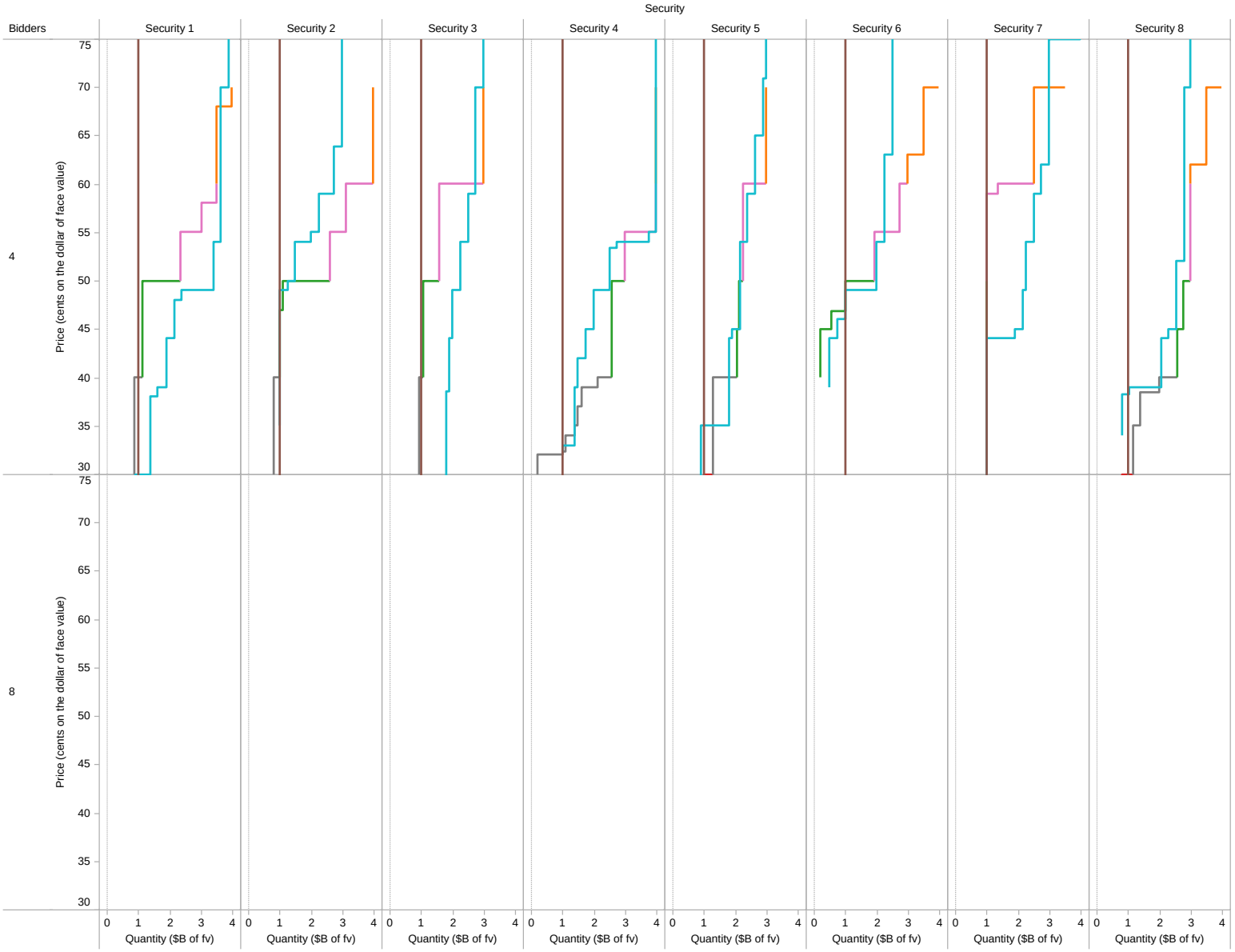


Figure A4.23. Supply and demand by number of bidders (day 2, auction a)

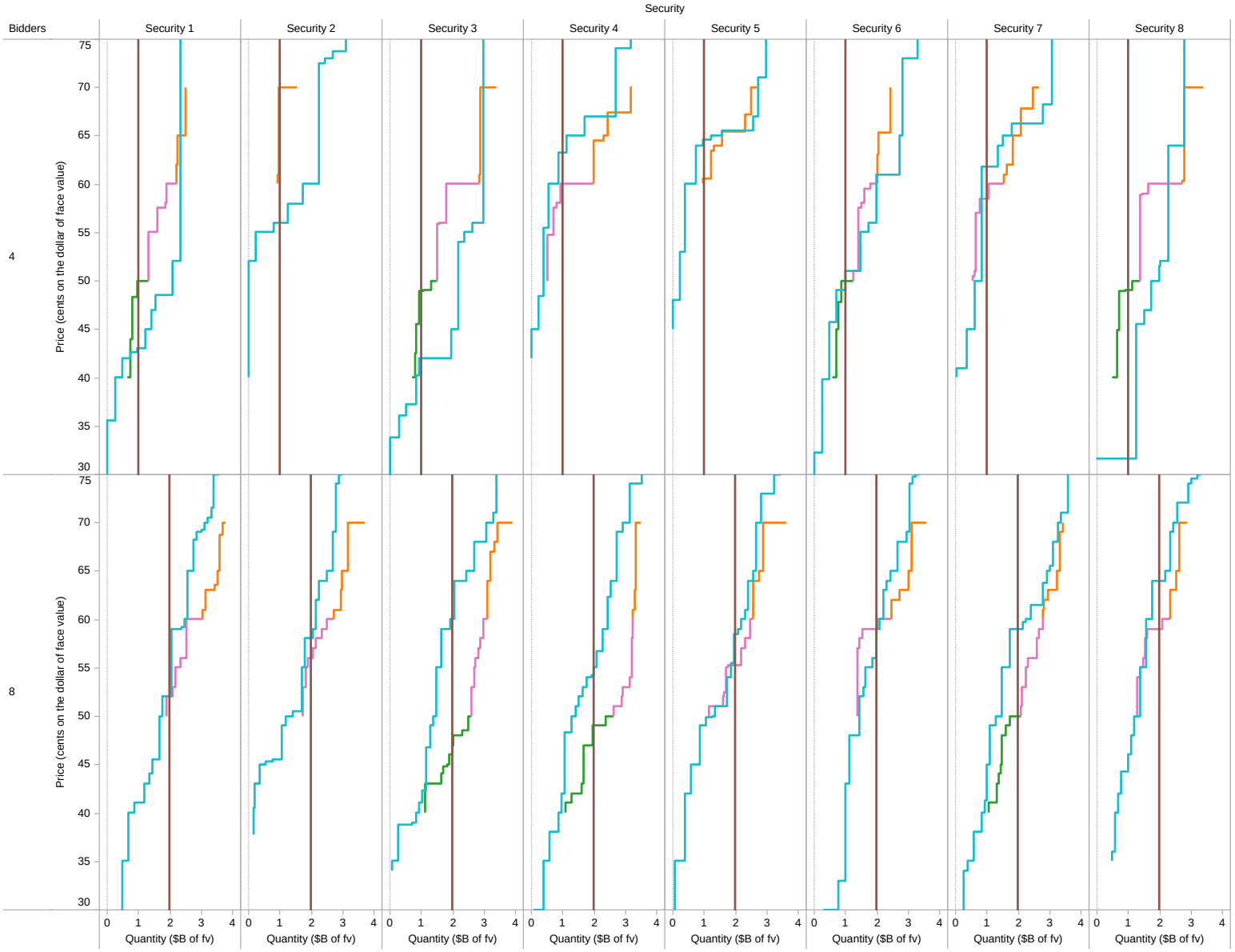


Figure A4.24. Supply and demand by number of bidders (day 2, auction b)

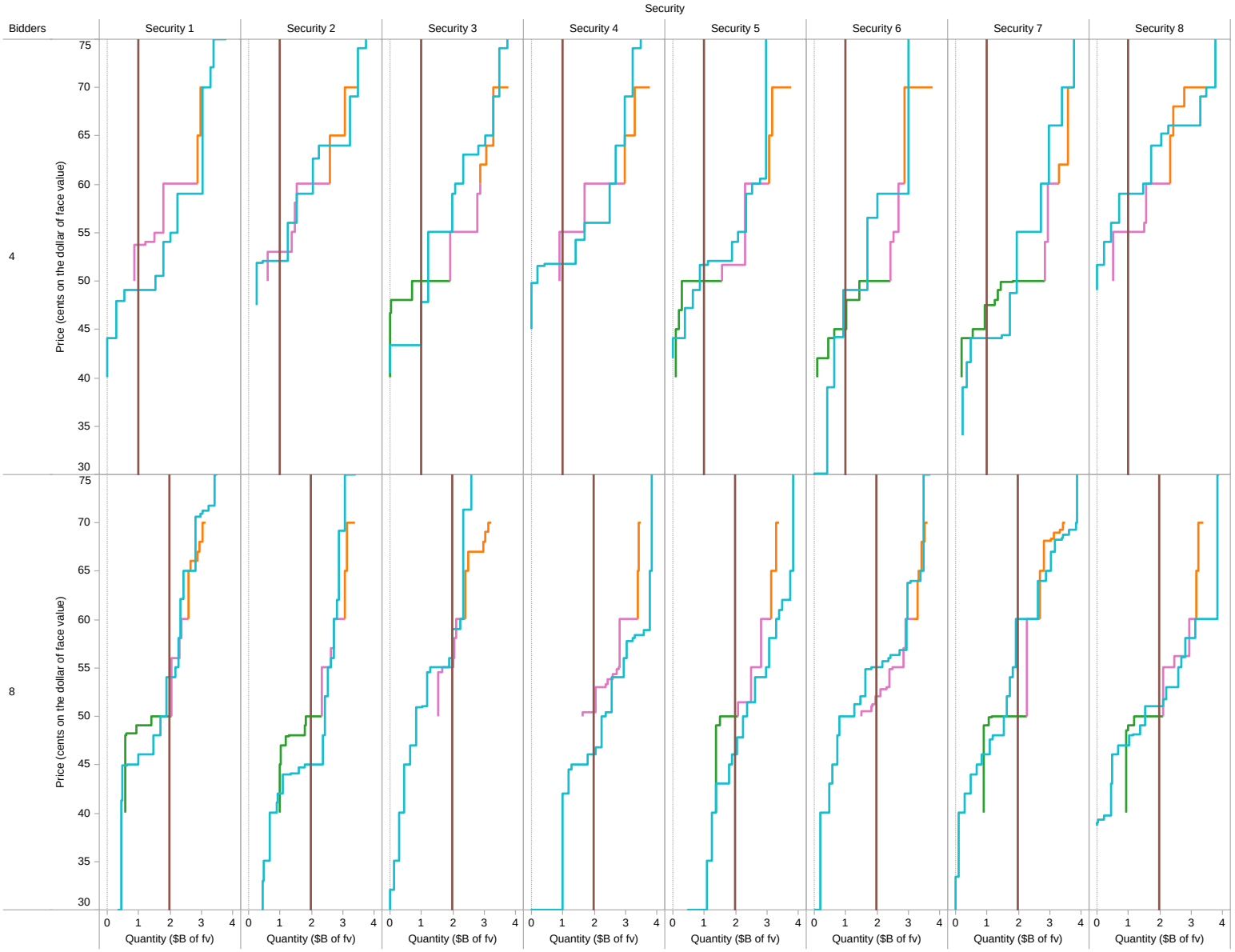


Figure A4.25. Supply and demand by number of bidders (day 2, auction c)

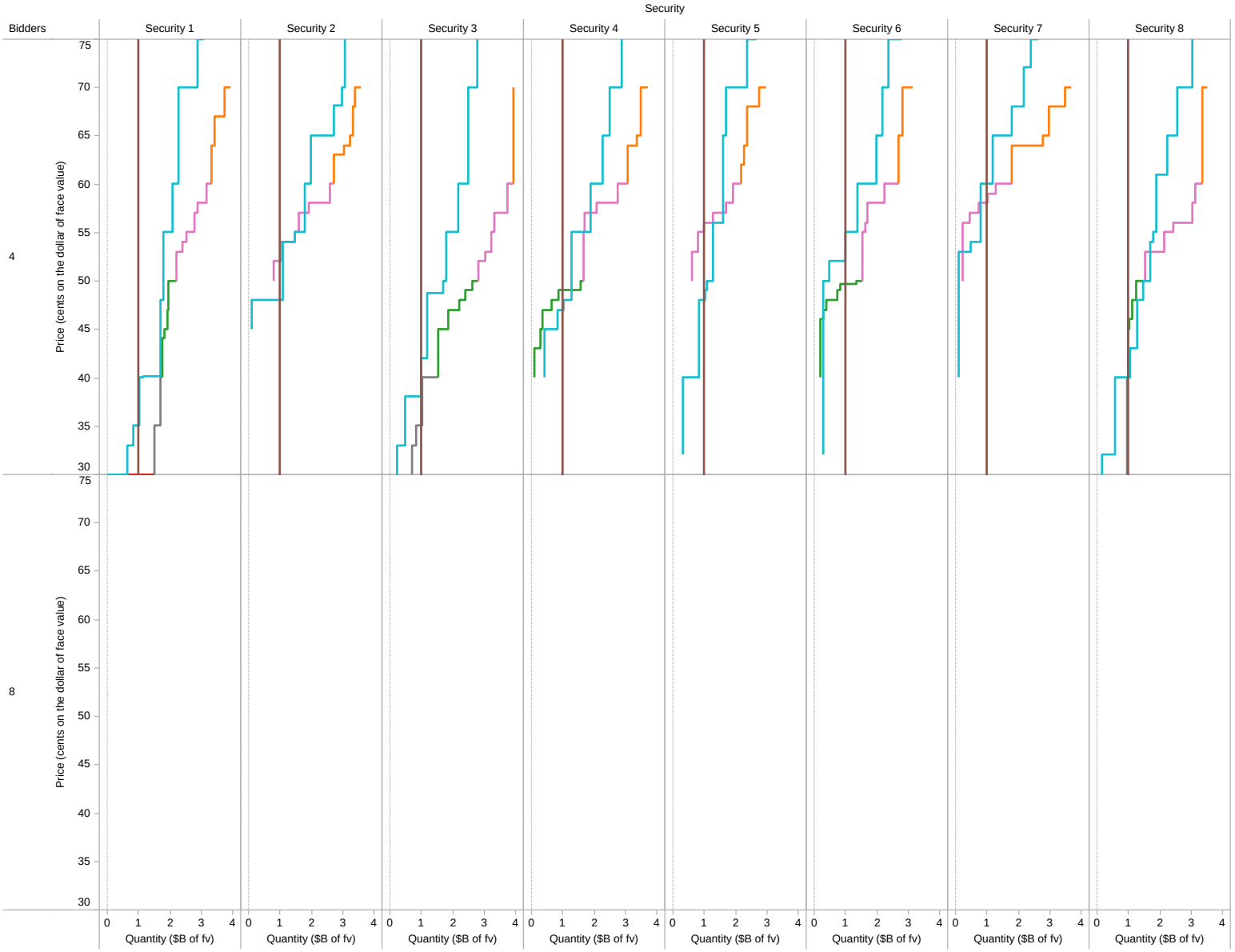


Figure A4.26. Supply and demand by number of bidders (day 2, auction d)

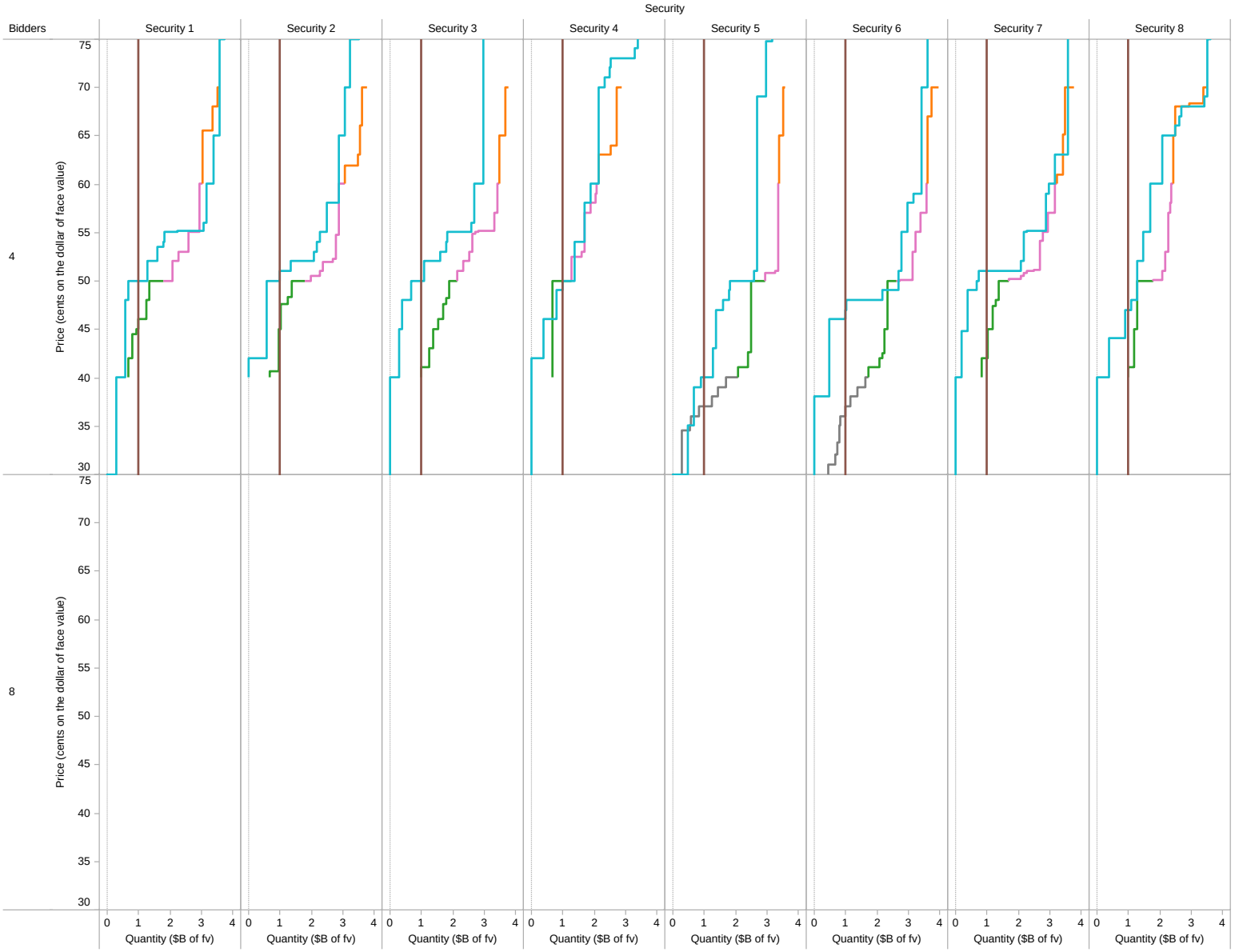


Figure A4.27. Supply and demand by number of bidders (day 3, auction a)

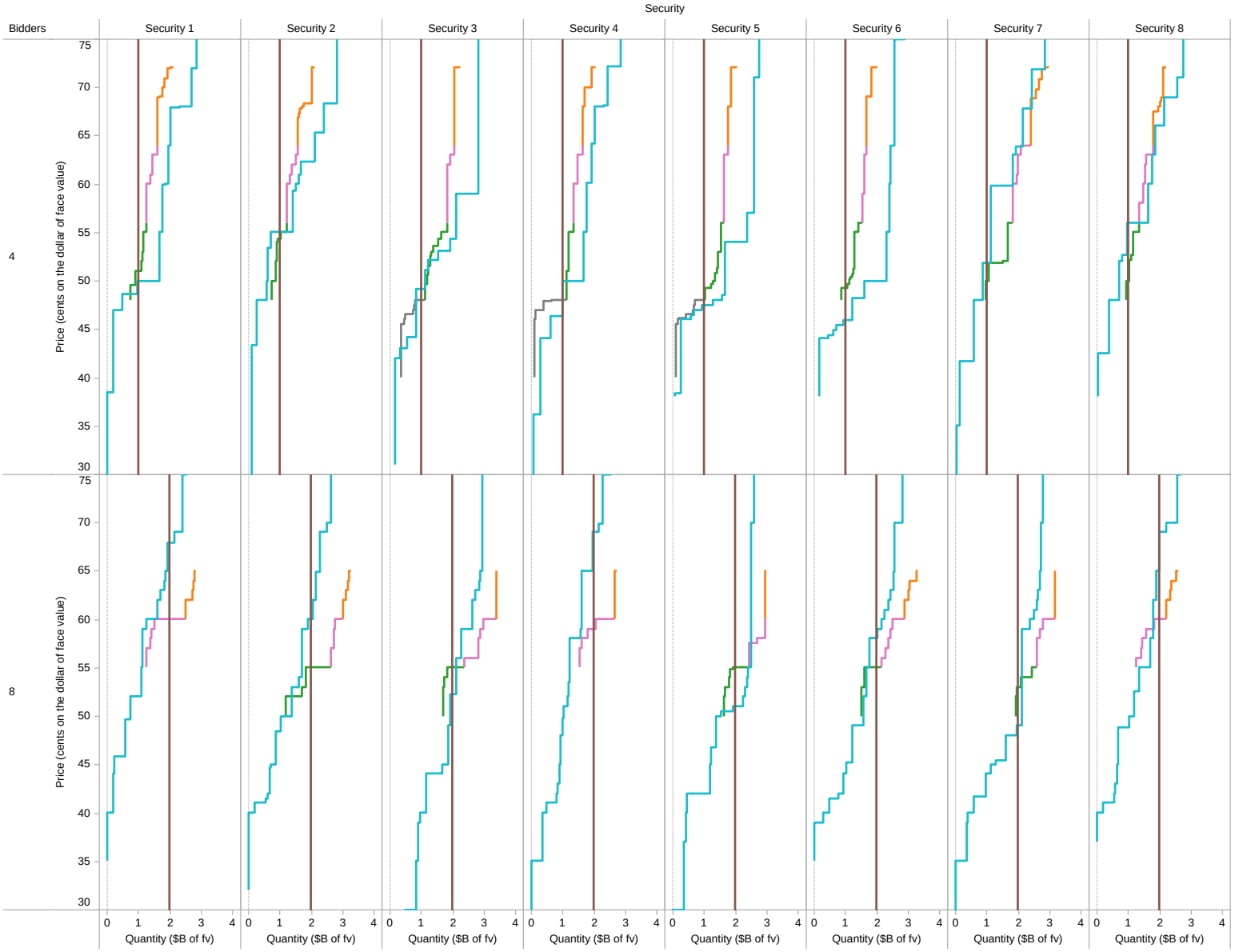


Figure A4.28. Supply and demand by number of bidders (day 3, auction b)

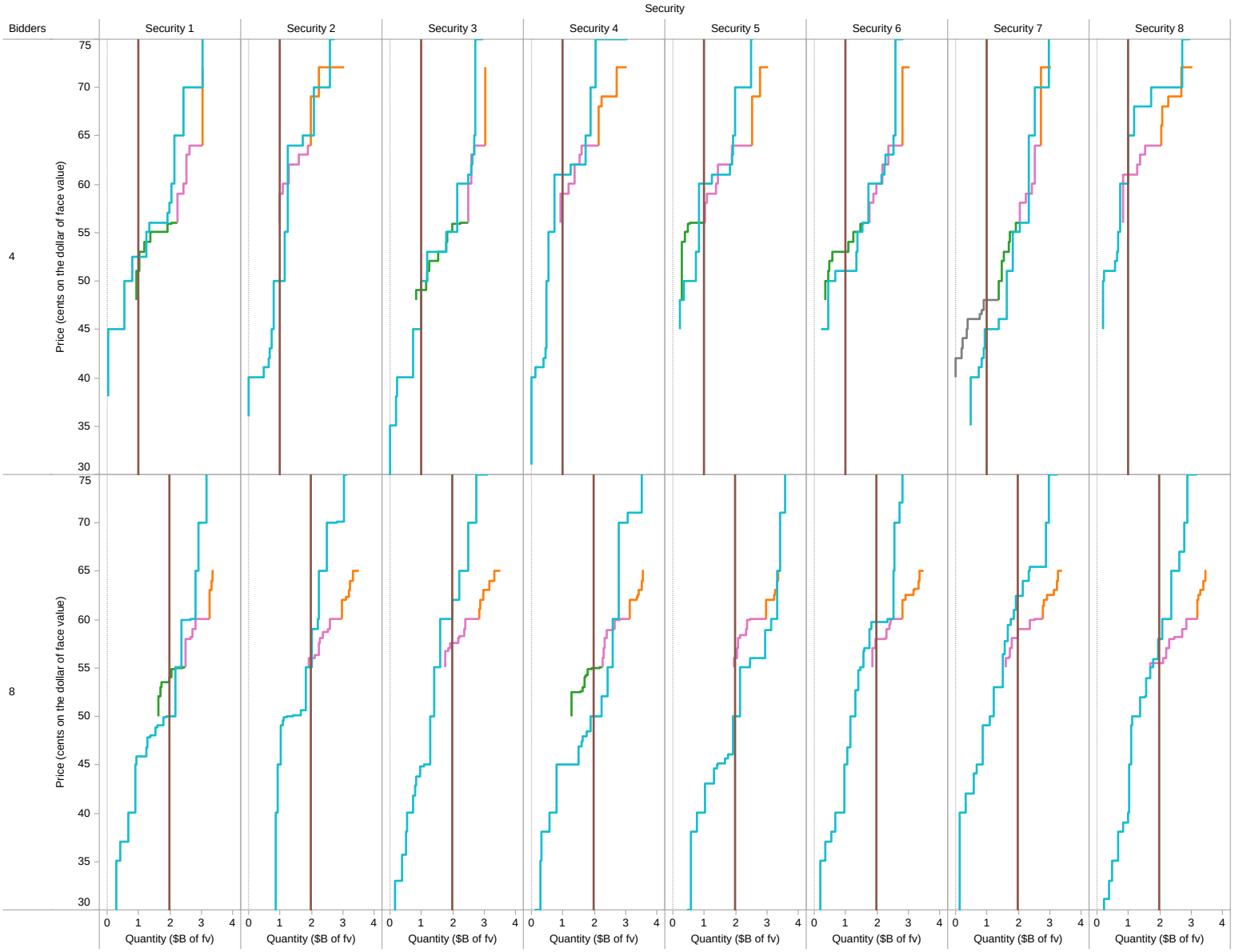


Figure A4.29. Supply and demand by number of bidders (day 3, auction c)

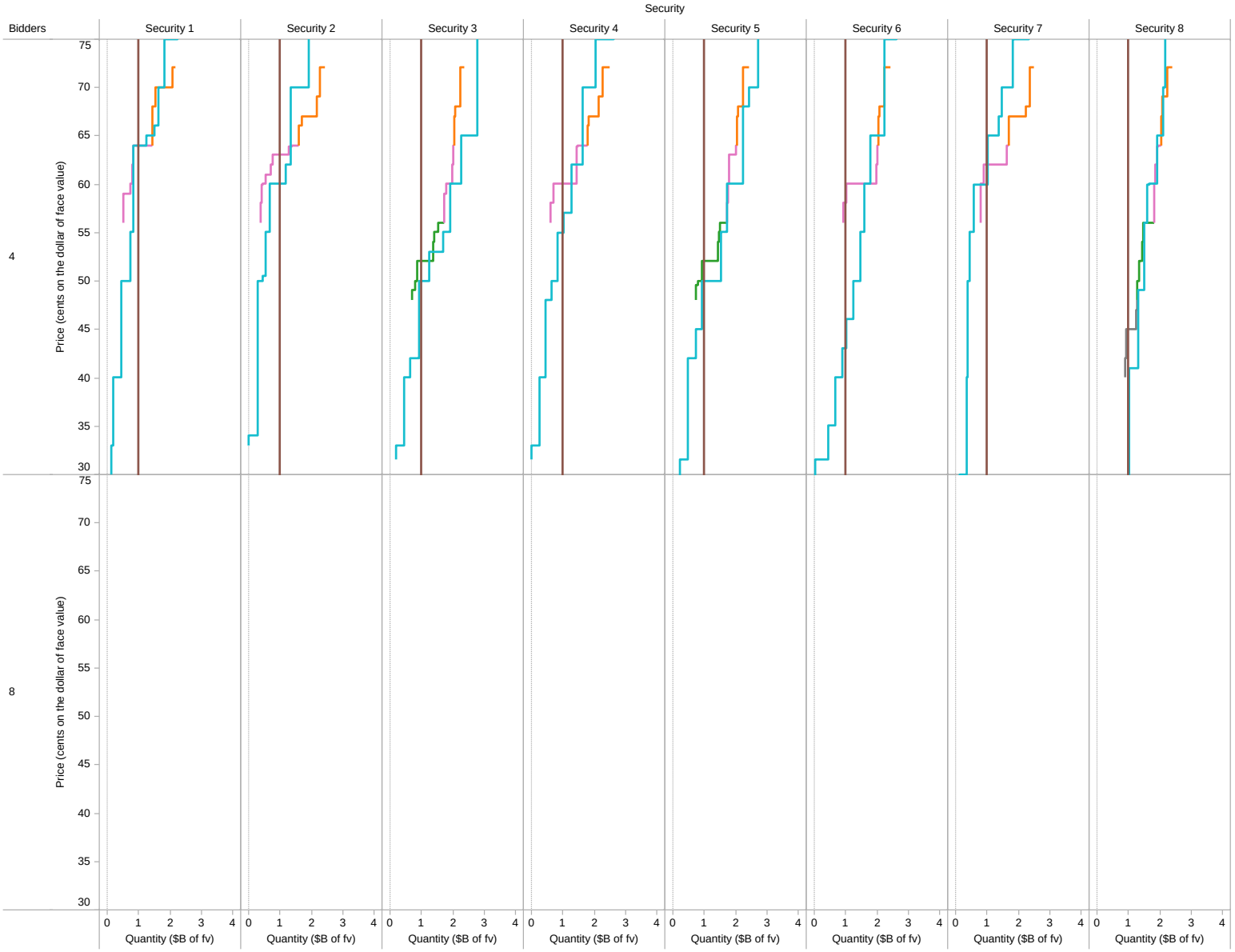


Figure A4.30. Supply and demand by number of bidders (day 3, auction d)

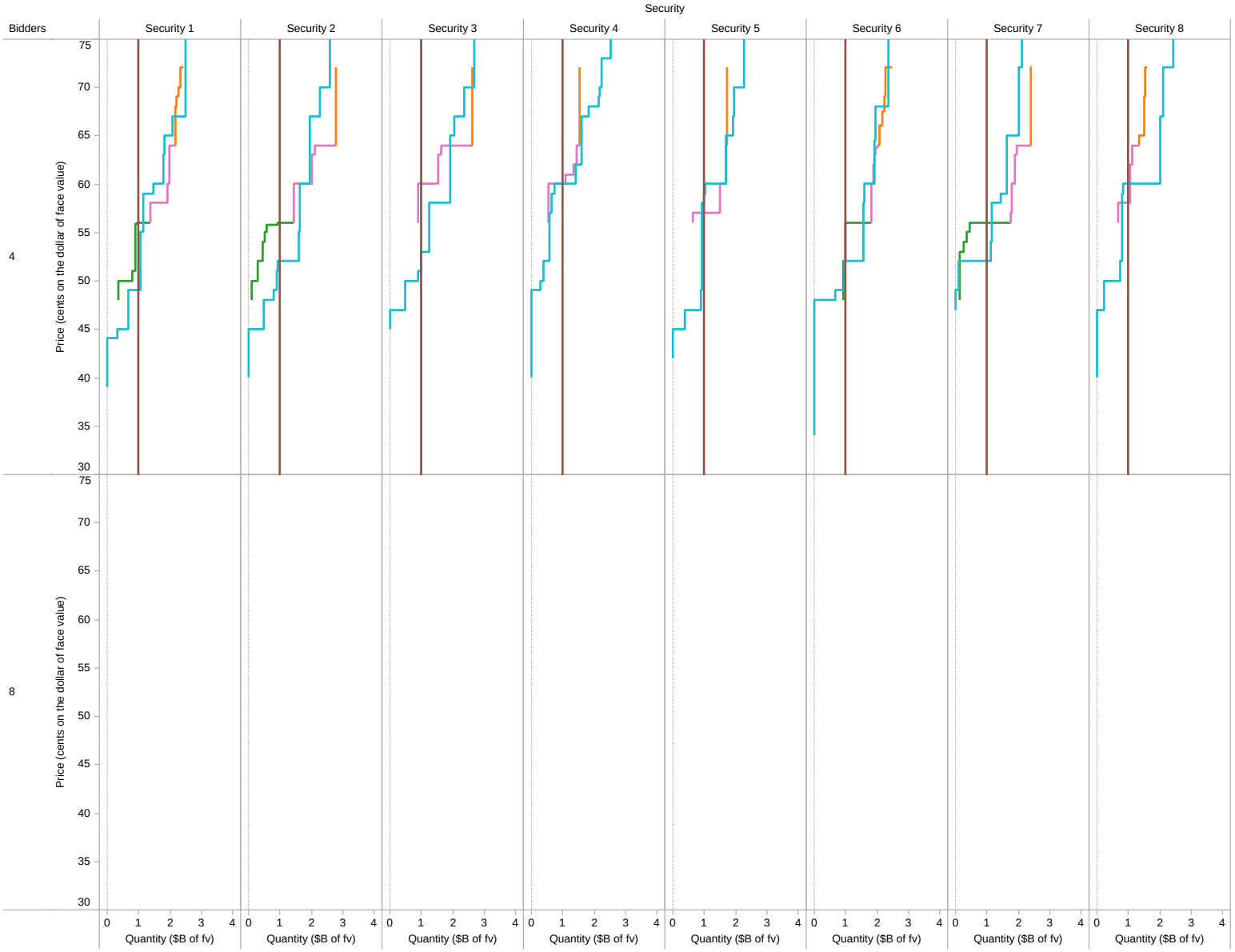


Figure A4.31. Supply and demand by number of bidders (day 4, auction a)

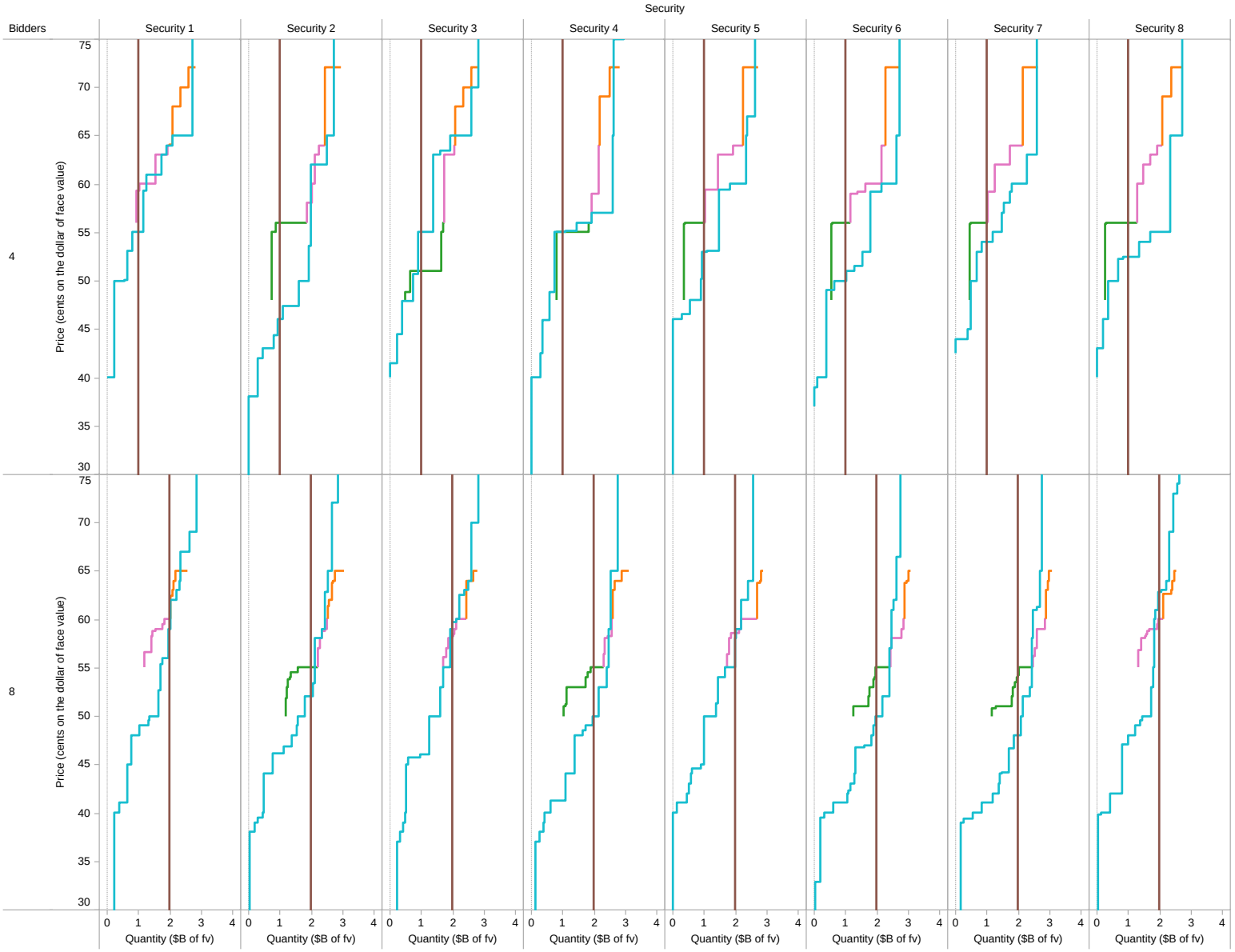


Figure A4.32. Supply and demand by number of bidders (day 4, auction b)

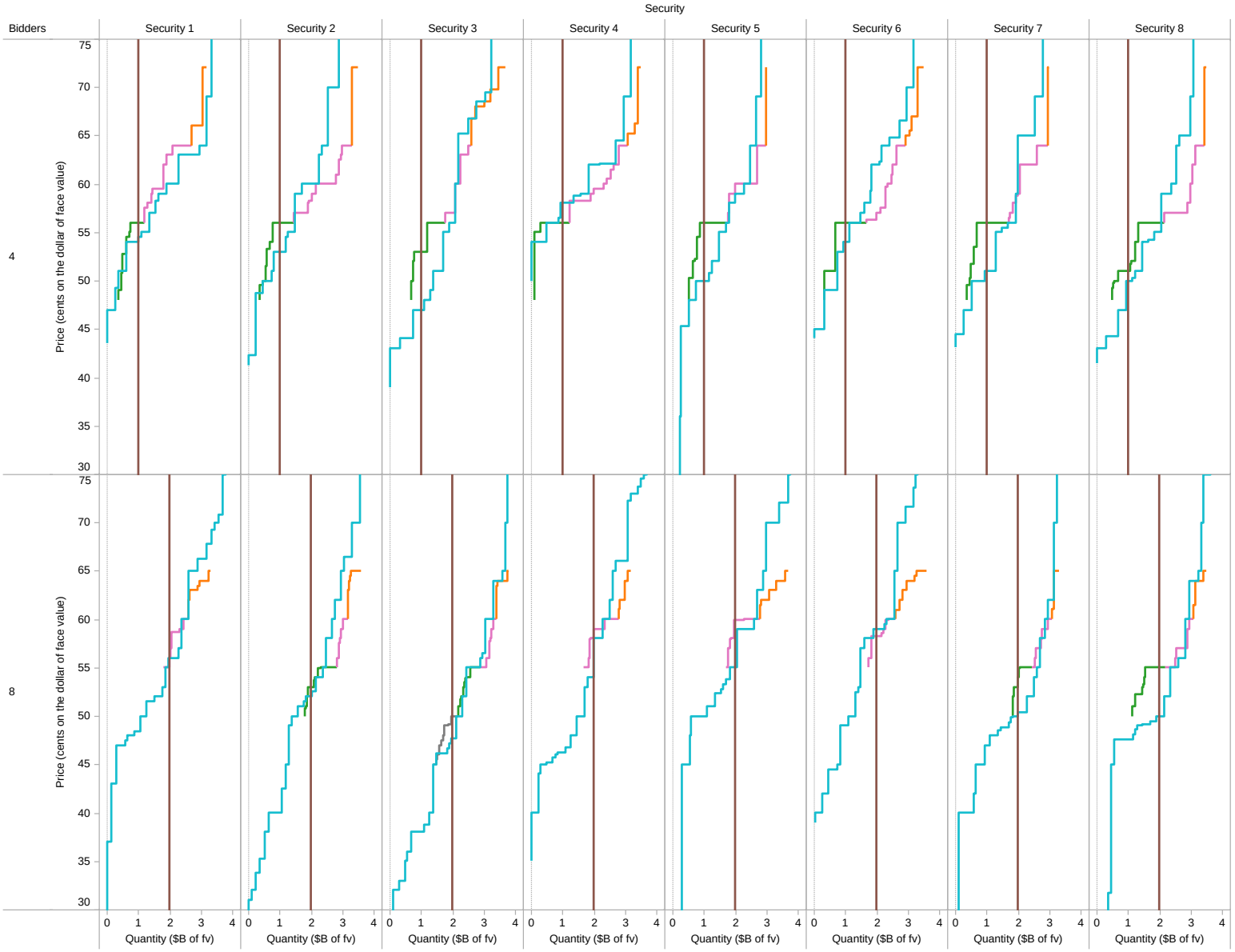


Figure A4.33. Supply and demand by number of bidders (day 4, auction c)

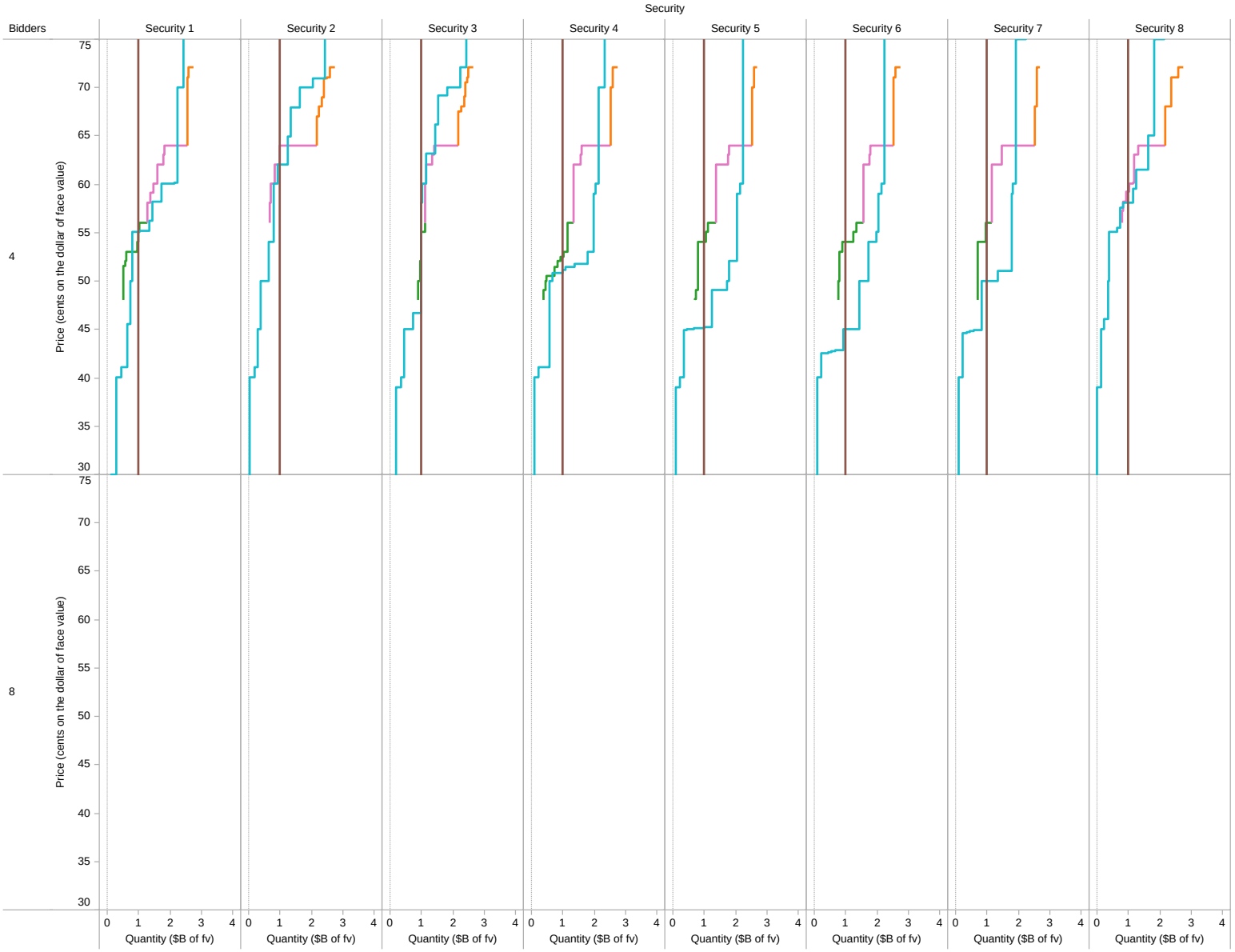
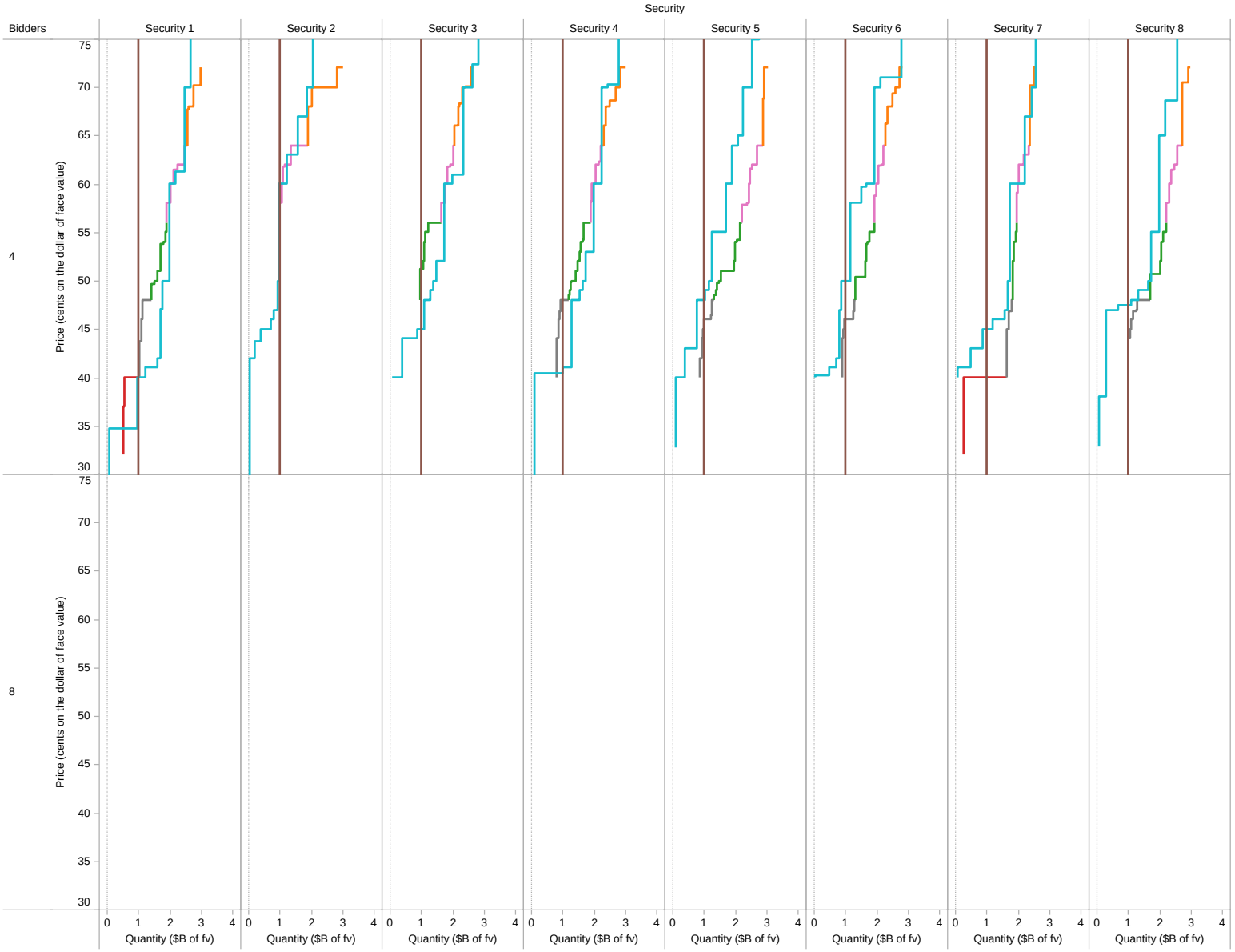


Figure A4.34. Supply and demand by number of bidders (day 4, auction d)



Appendix 5

Figures from Experiment 2: Reference-Price Auctions

Figure A5.0. Payoff as a function of liquidity

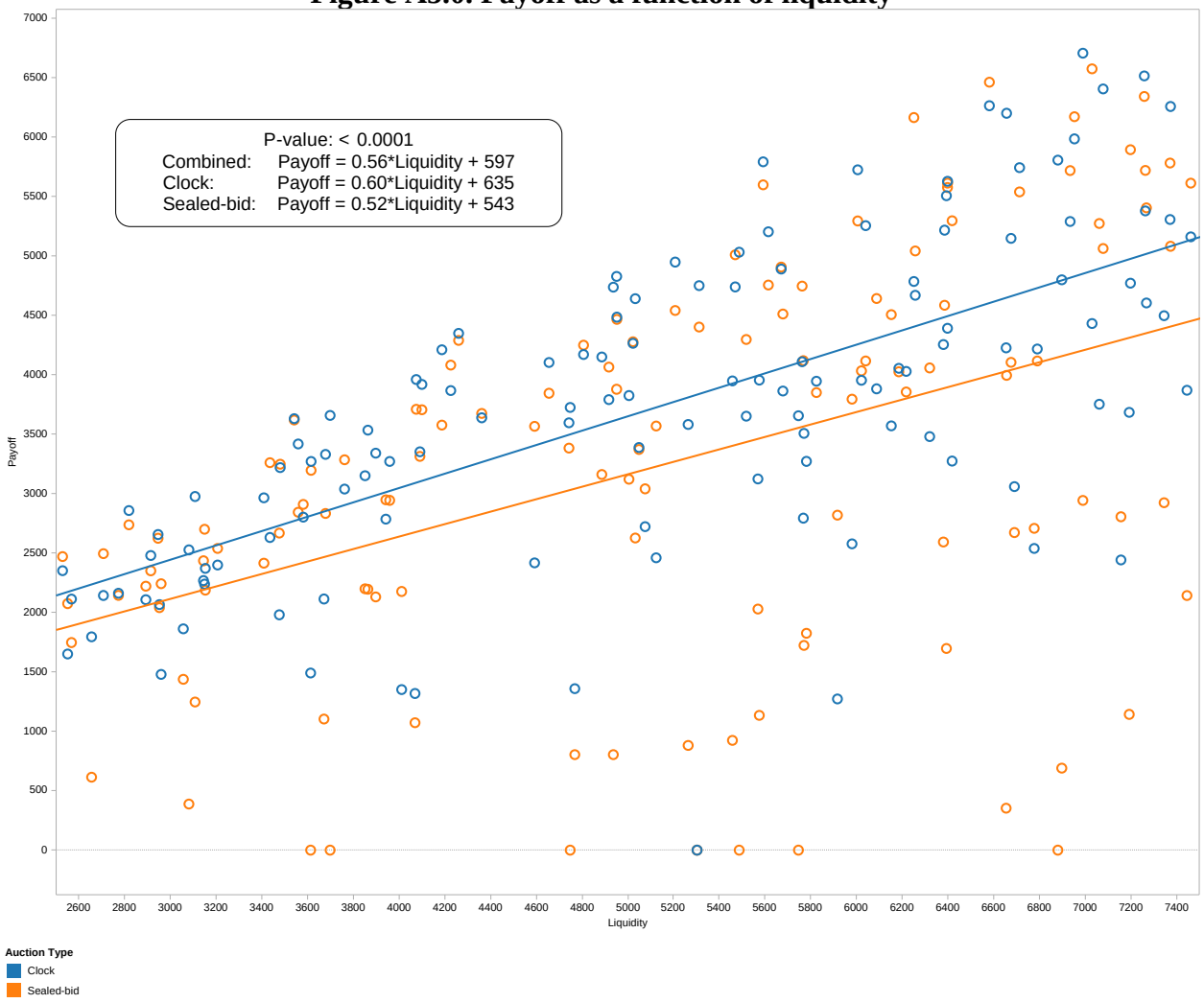


Figure A5.1. Price minus true value by session, precision, and auction

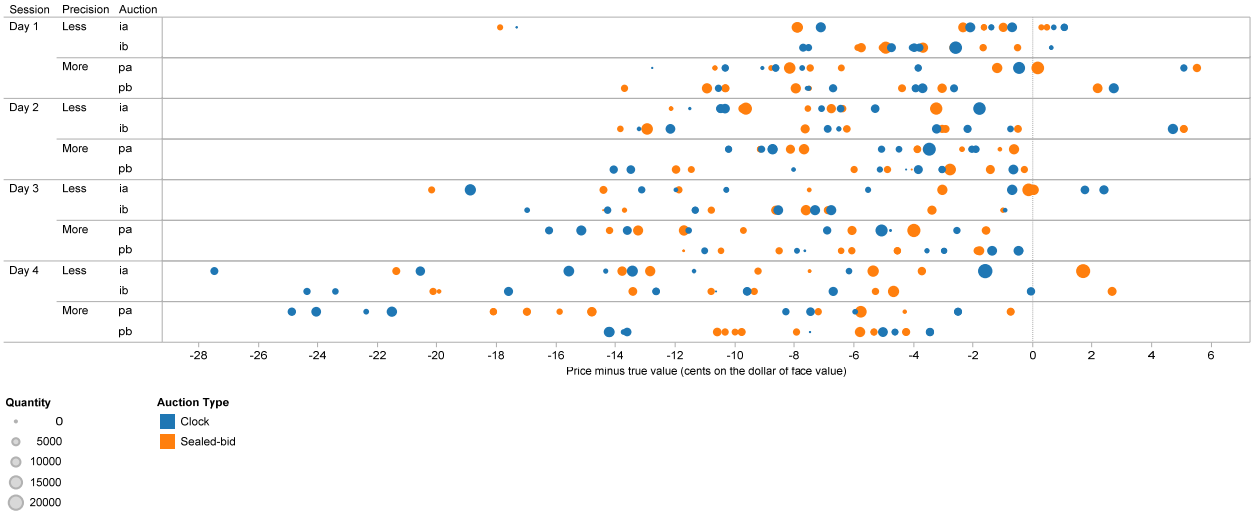


Figure A5.2. Profit by session, precision, auction, and bidder

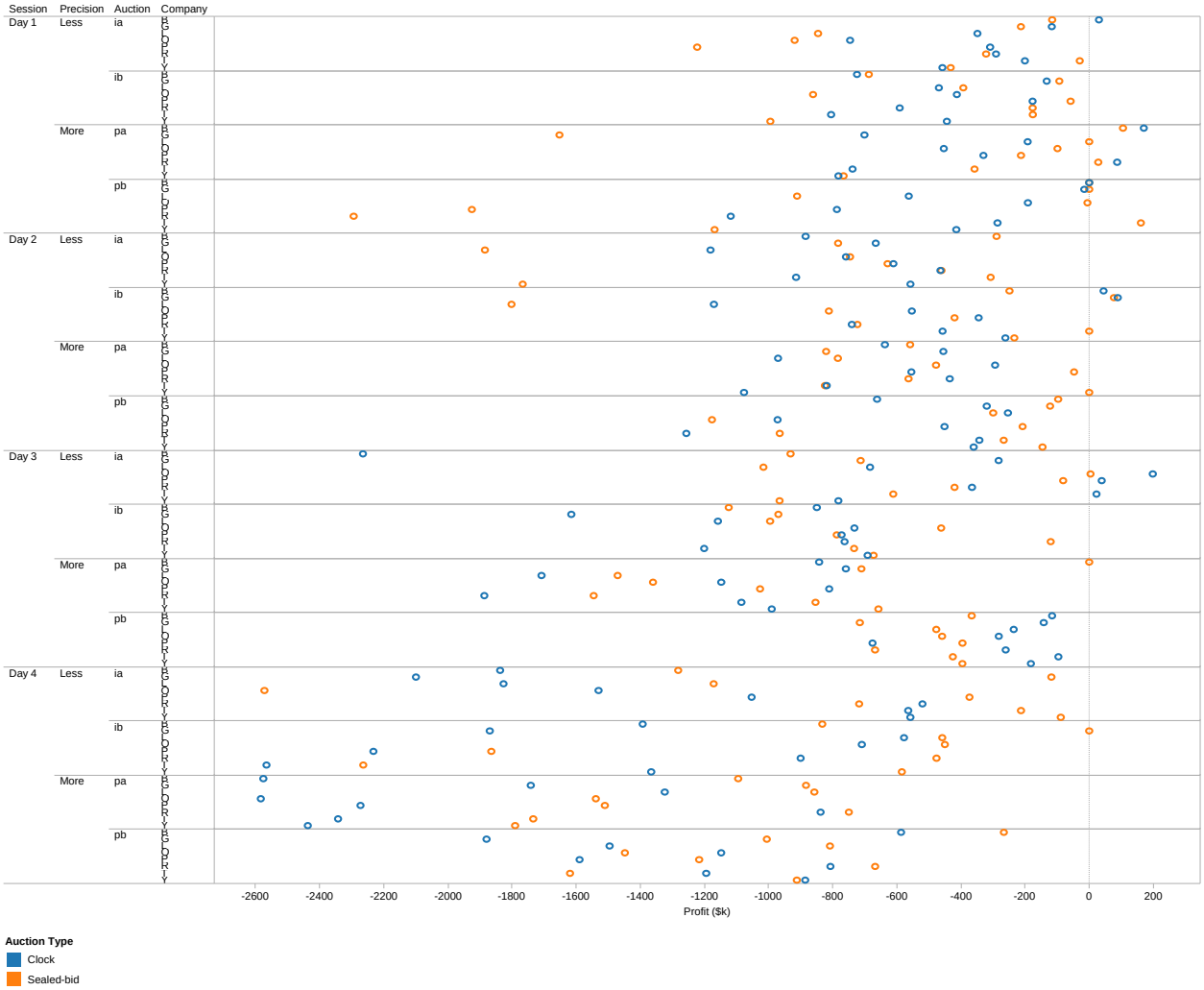


Figure A5.3. Average profit across bidders by session, precision, and auction

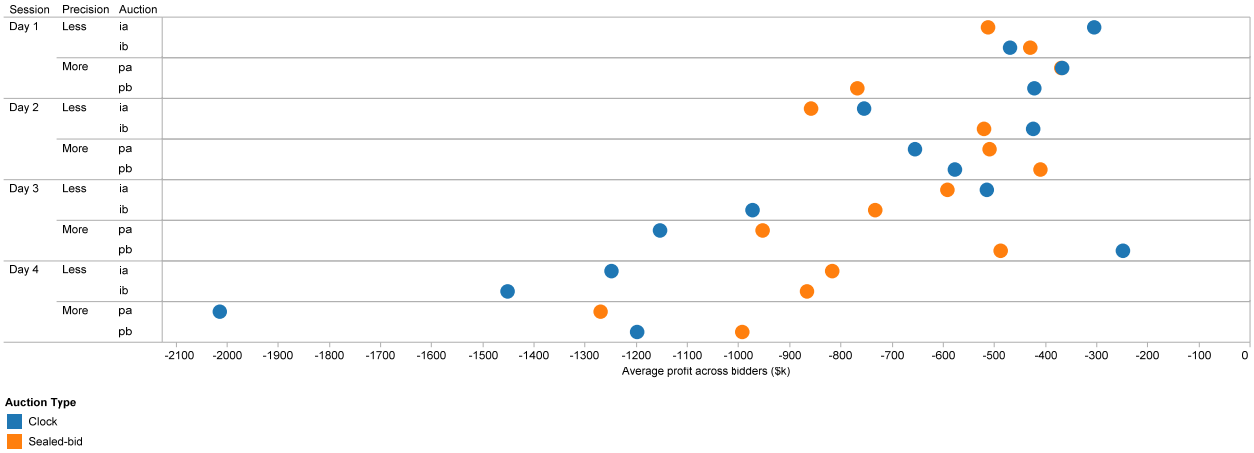


Figure A5.4. Average profit across bidders and auctions by session and precision

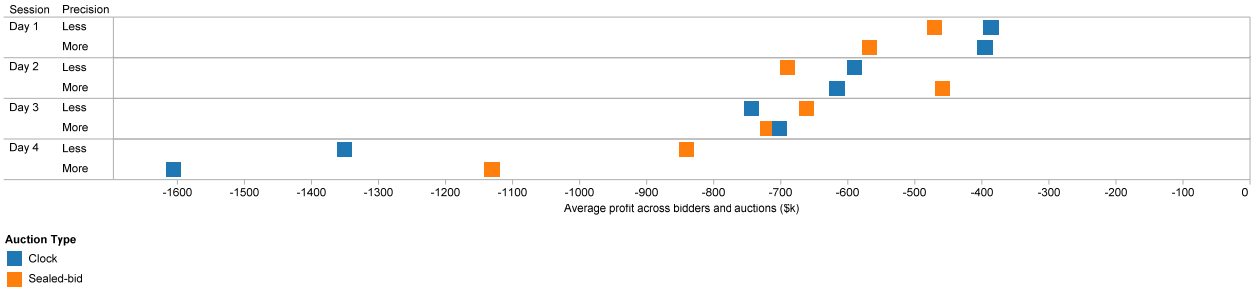


Figure A5.5. Average profit across bidders, auctions, and sessions by precision

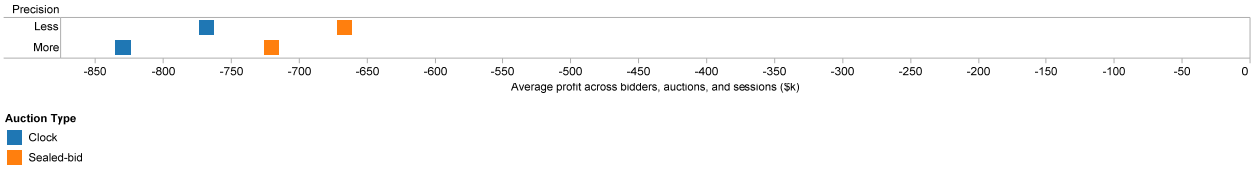


Figure A5.6. Liquidity bonus by session, precision, auction, and bidder

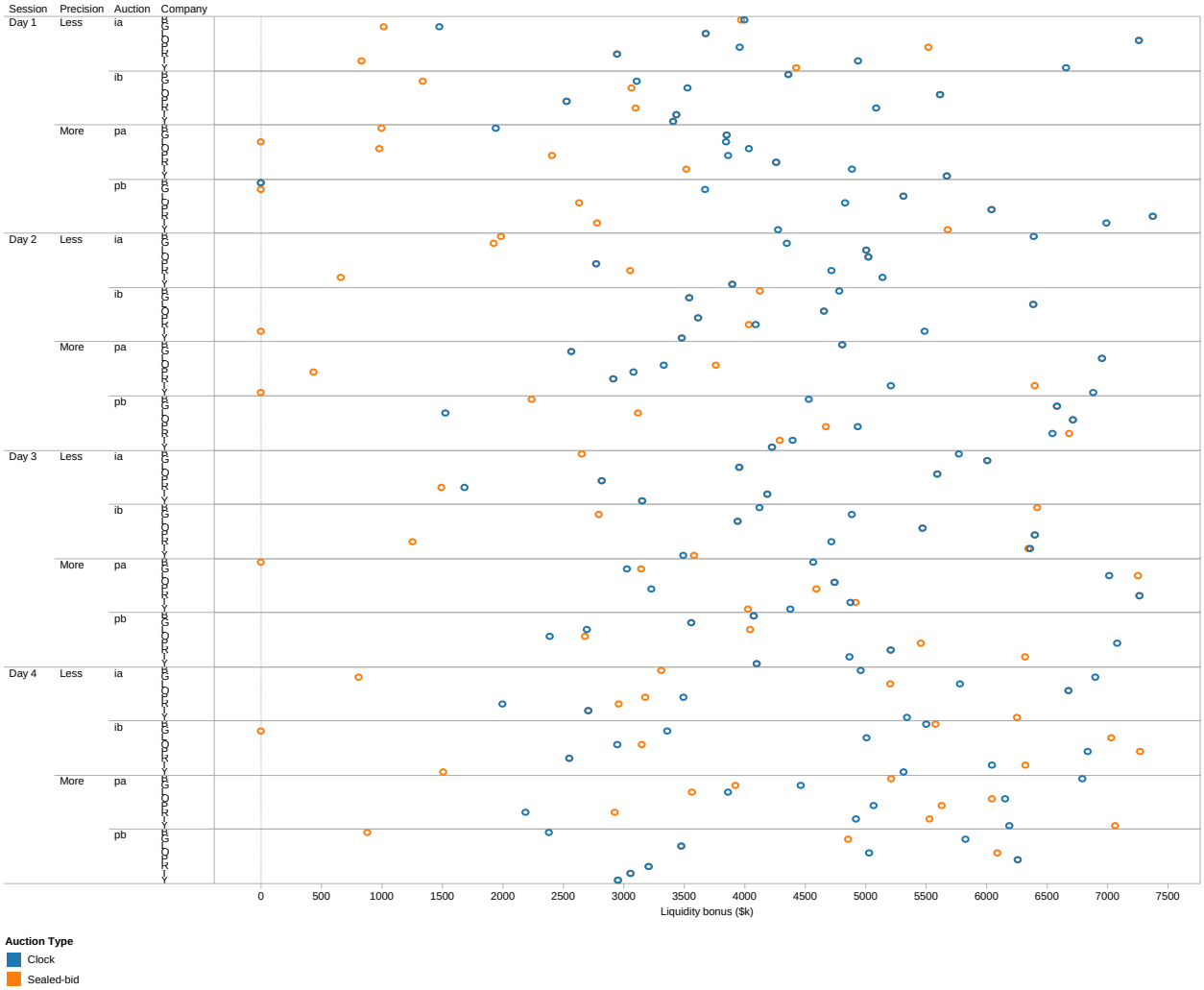


Figure A5.7. Average liquidity bonus across bidders by session, precision, and auction

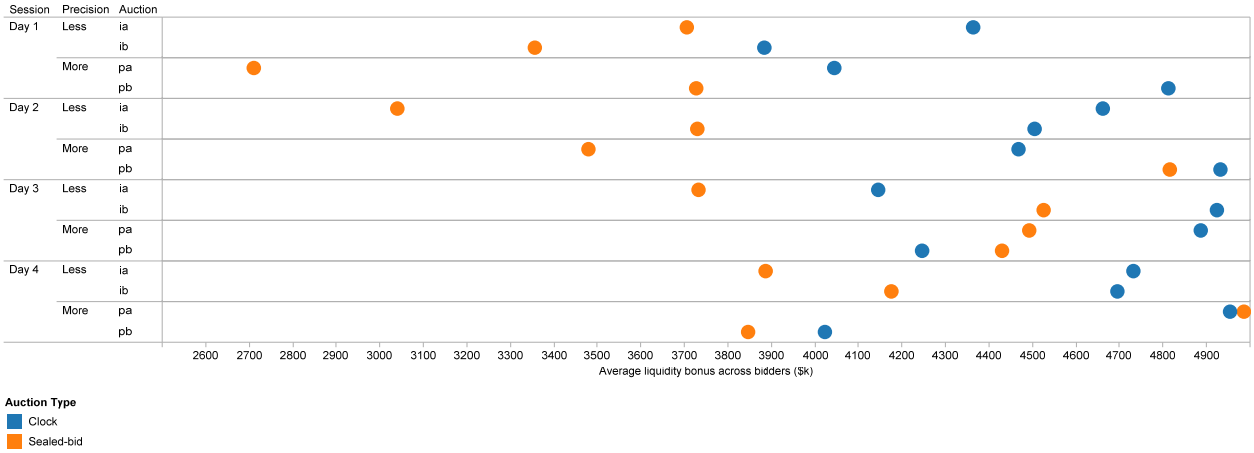


Figure A5.8. Average liquidity bonus across bidders and auctions by session and precision

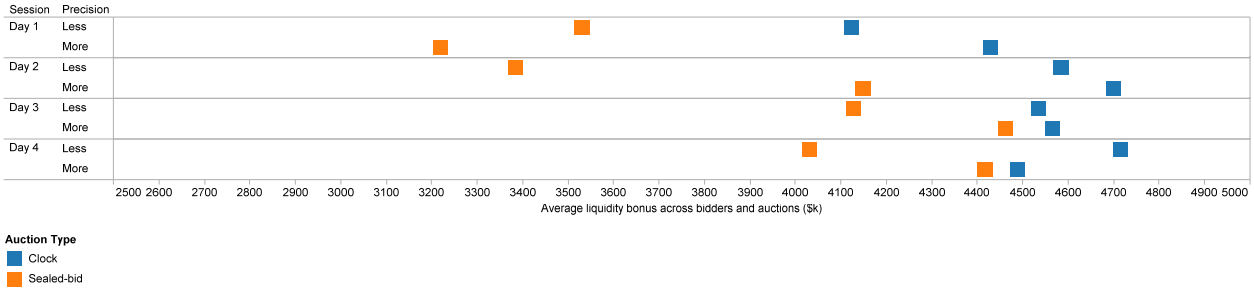


Figure A5.9. Average liquidity bonus across bidders, auctions, and sessions by precision

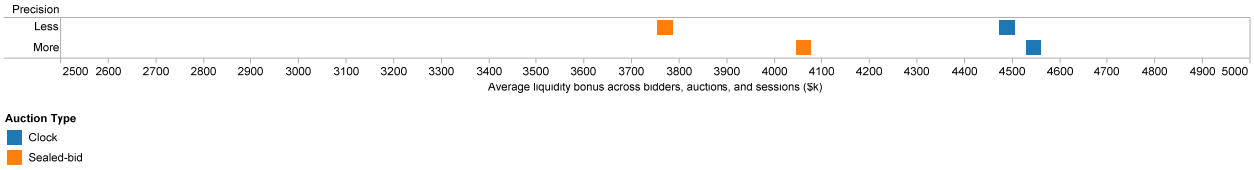


Figure A5.10. Payoff by session, precision, auction, and bidder

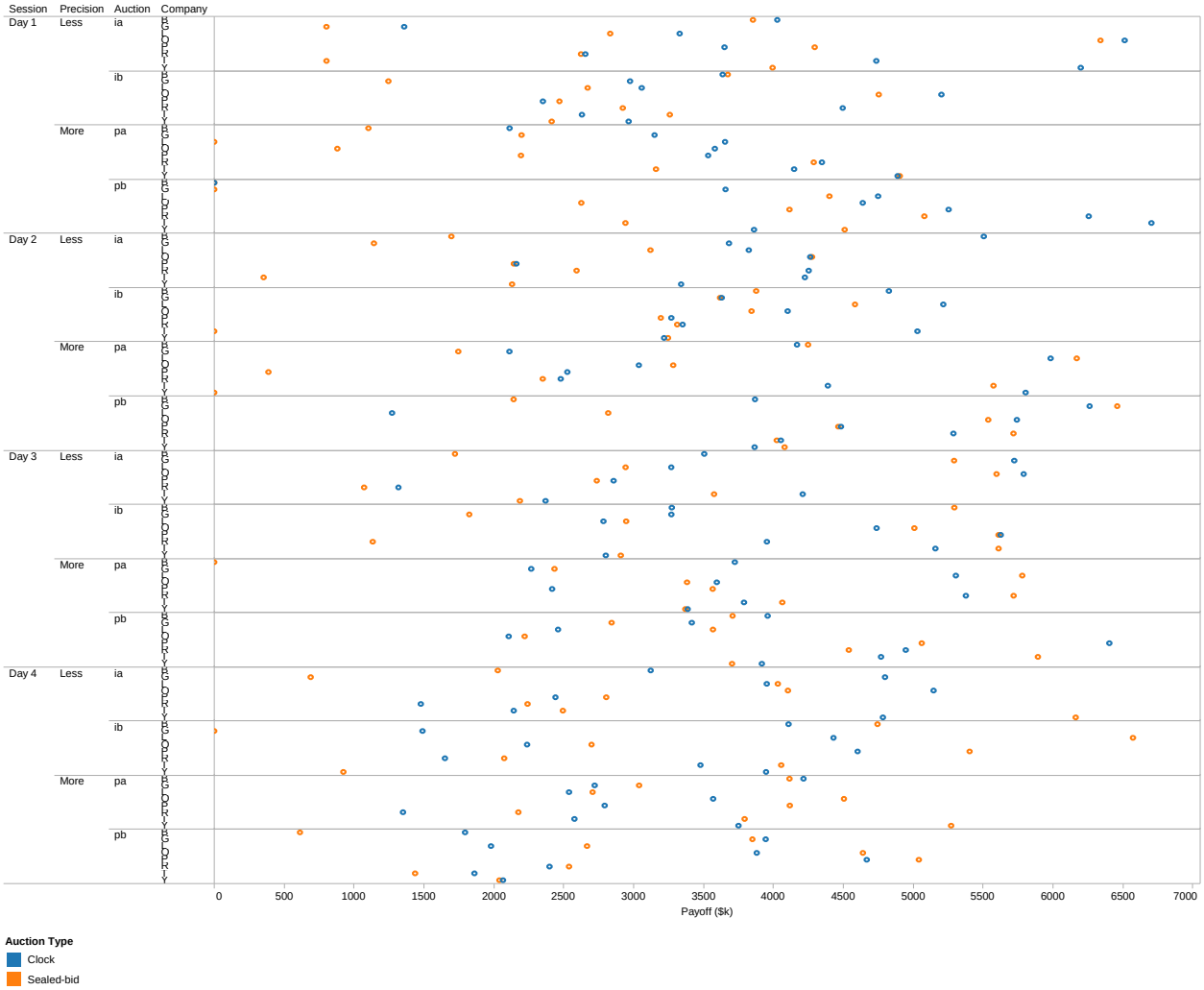


Figure A5.11. Average payoff across bidders by session, precision, and auction

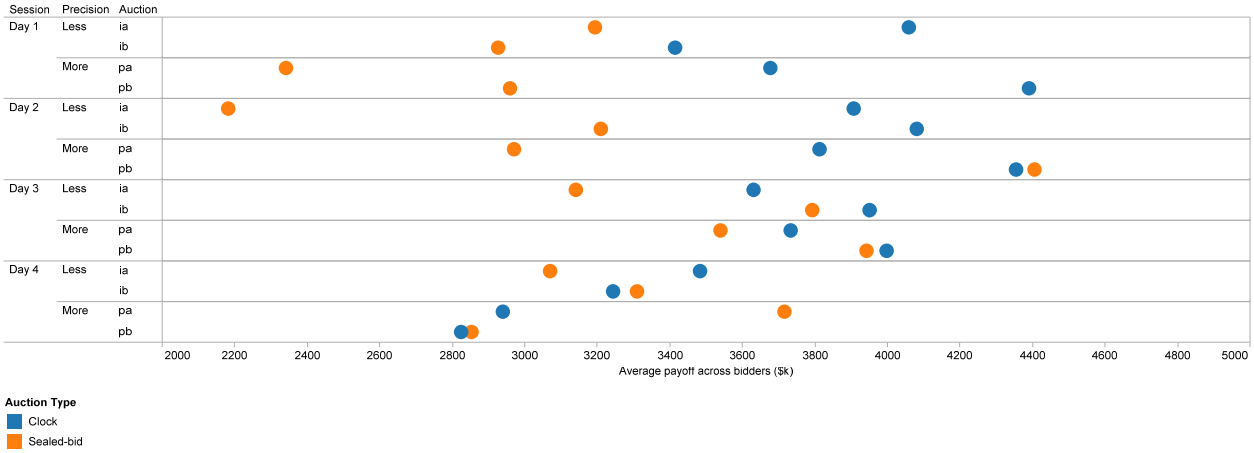


Figure A5.12. Average payoff across bidders and auctions by session and precision

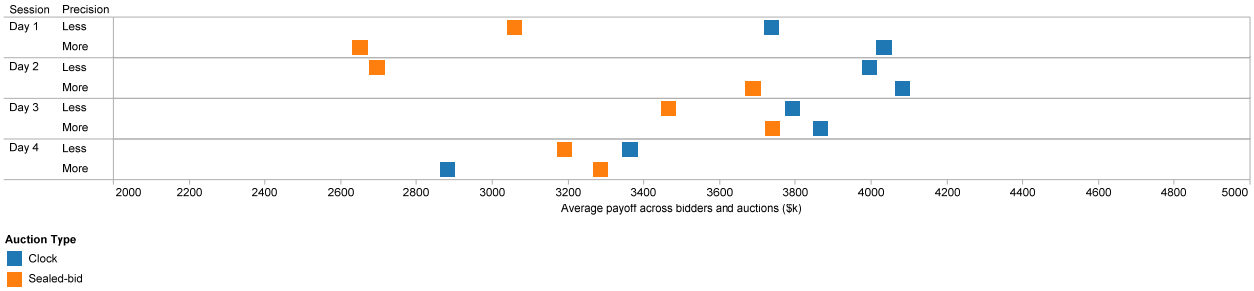


Figure A5.13. Average payoff across bidders, auctions, and sessions by precision

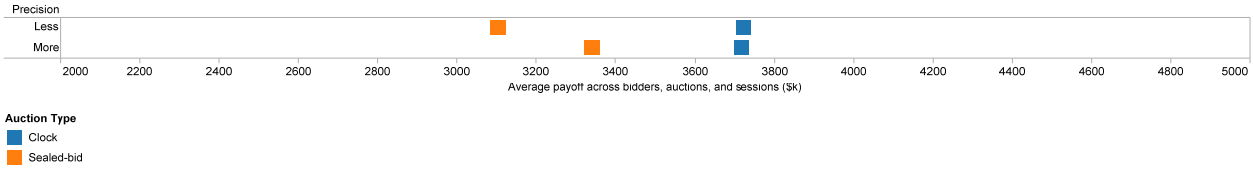


Figure A5.14. Standard deviation of profit across bidders by session and precision

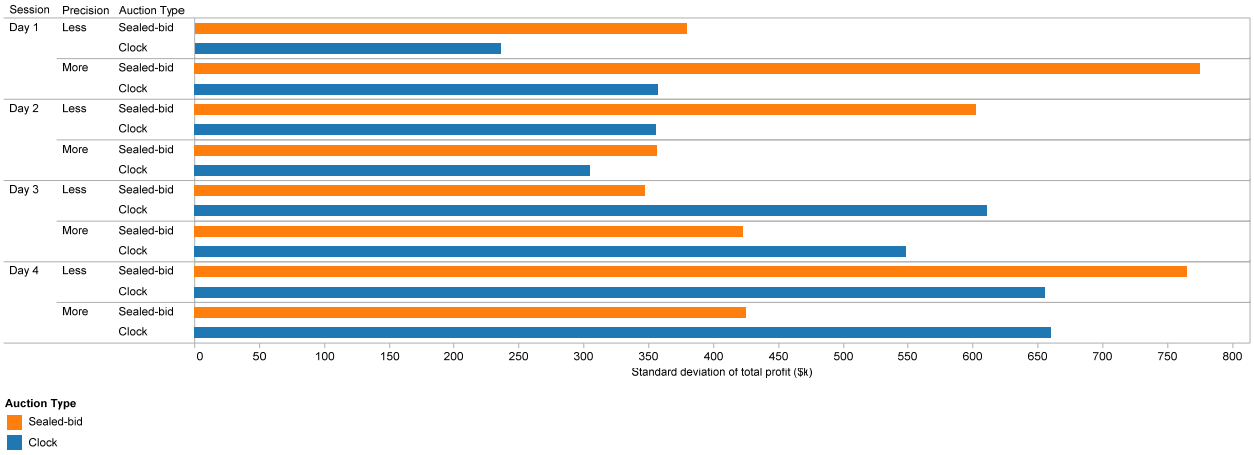


Figure A5.15. Standard deviation of profit across bidders and sessions by precision

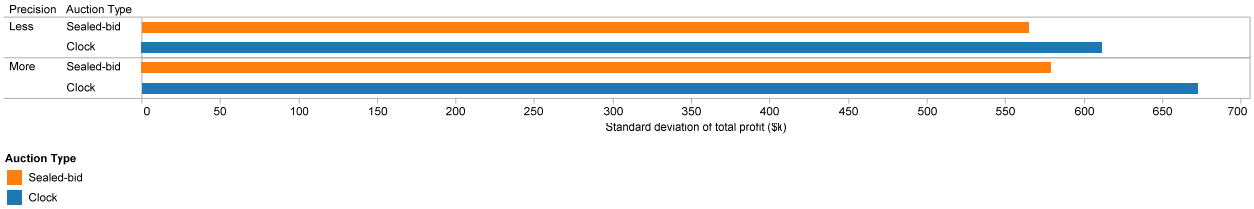


Figure A5.16. Standard deviation of liquidity bonus across bidders by session and precision

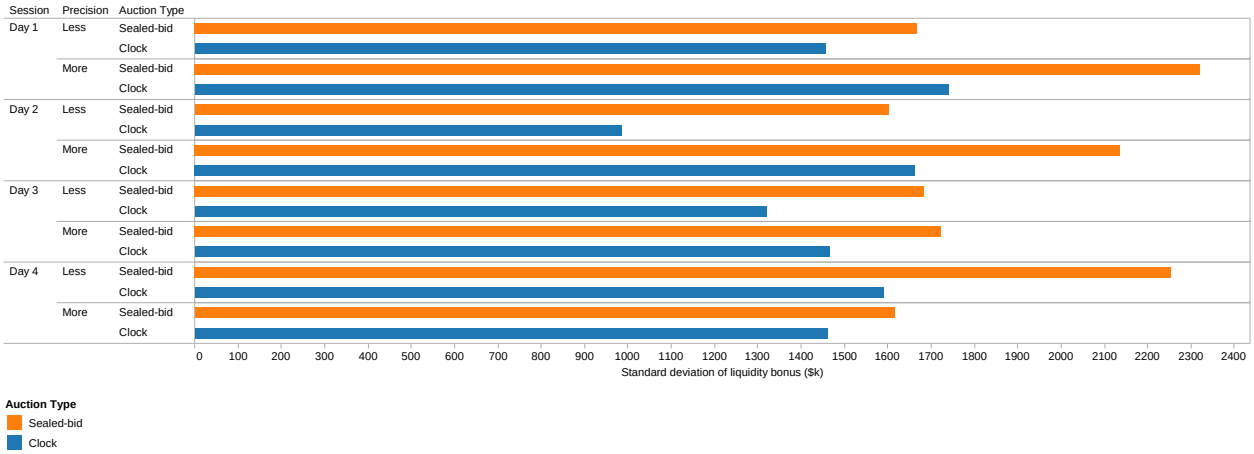


Figure A5.17. Standard deviation of liquidity bonus bidders and sessions by precision

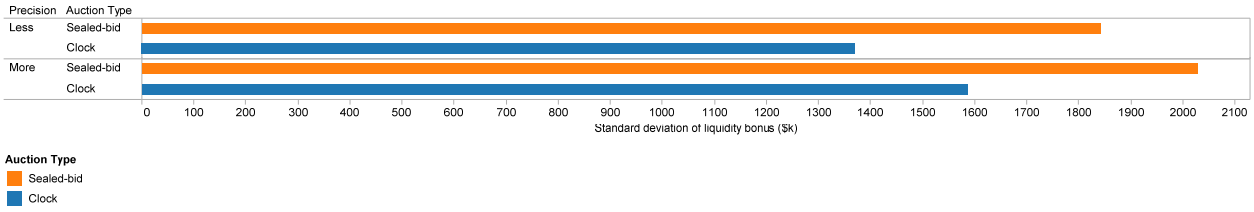


Figure A5.18. Standard deviation of payoff bidders by session and precision

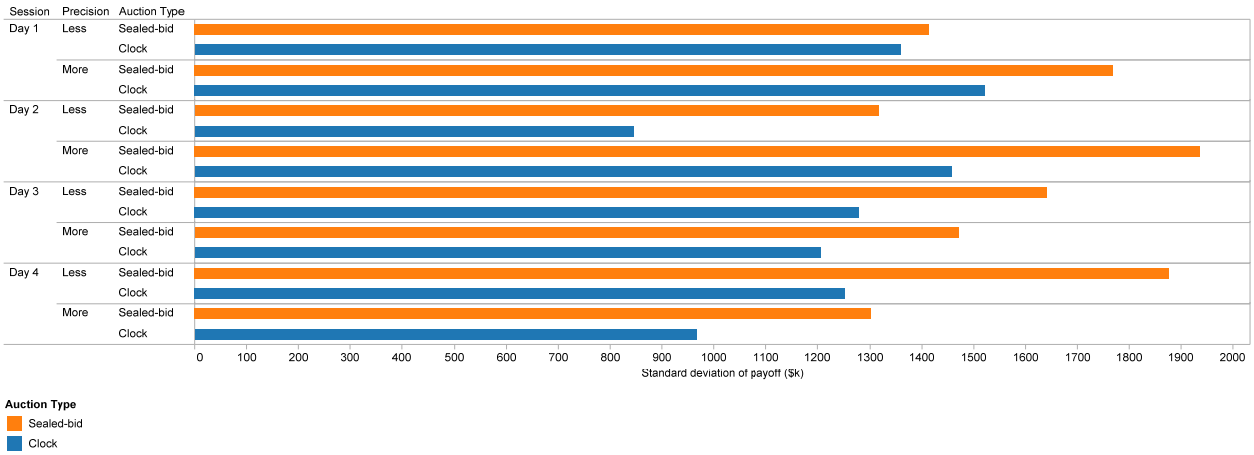


Figure A5.19. Standard deviation of payoff across bidders and sessions by precision

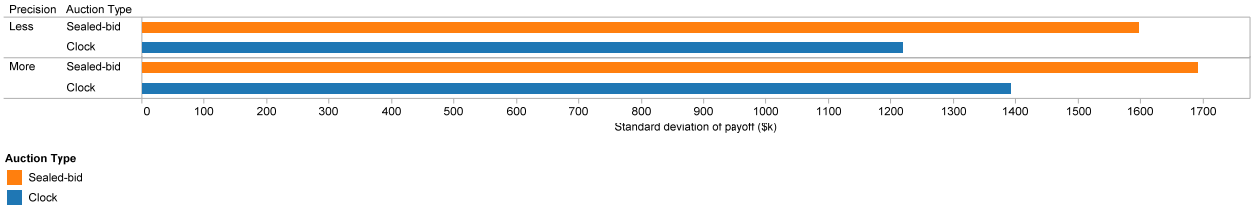


Figure A5.20. Supply and demand by pool and precision (day 1, auction a)

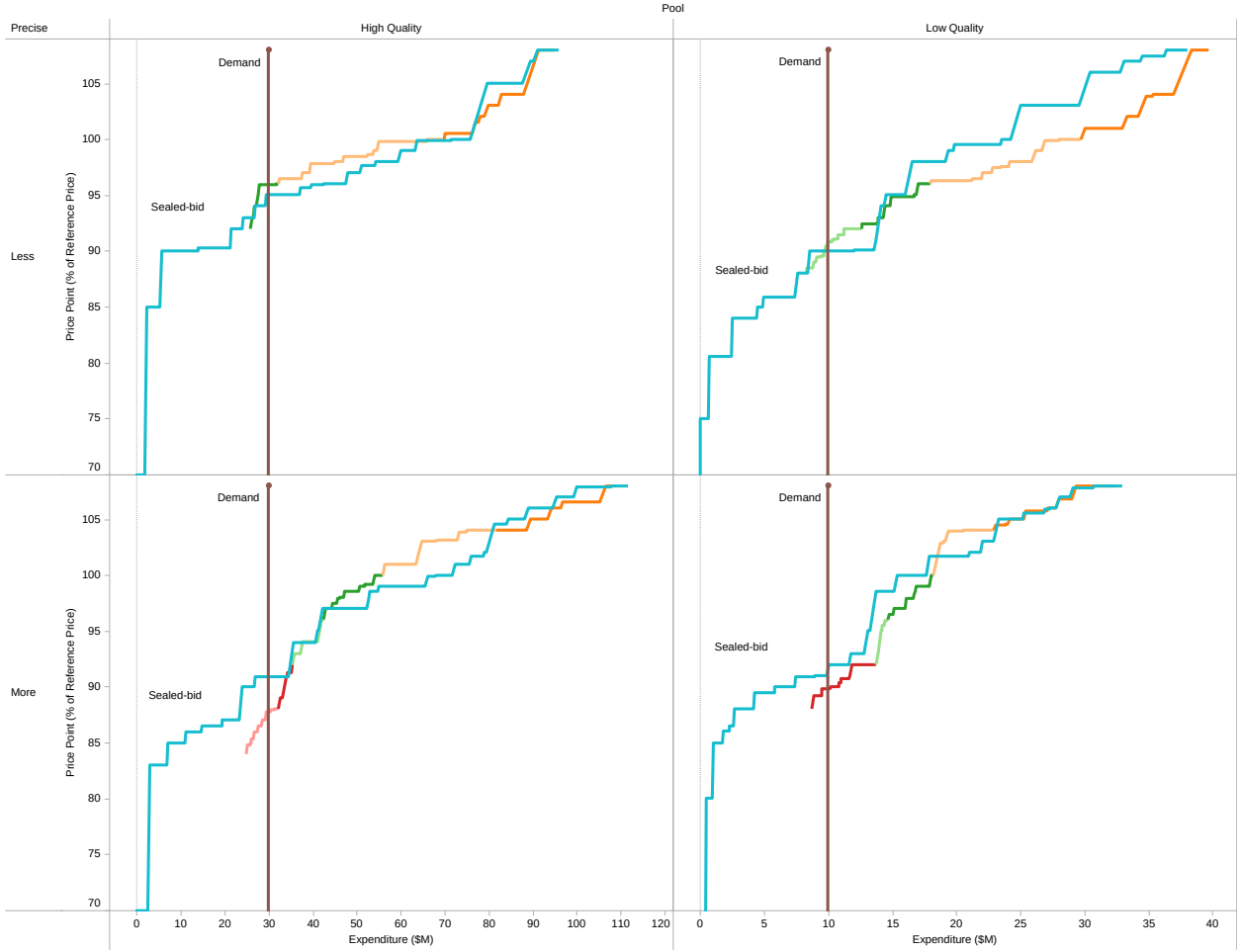


Figure A5.21. Supply and demand by pool and precision (day 1, auction b)

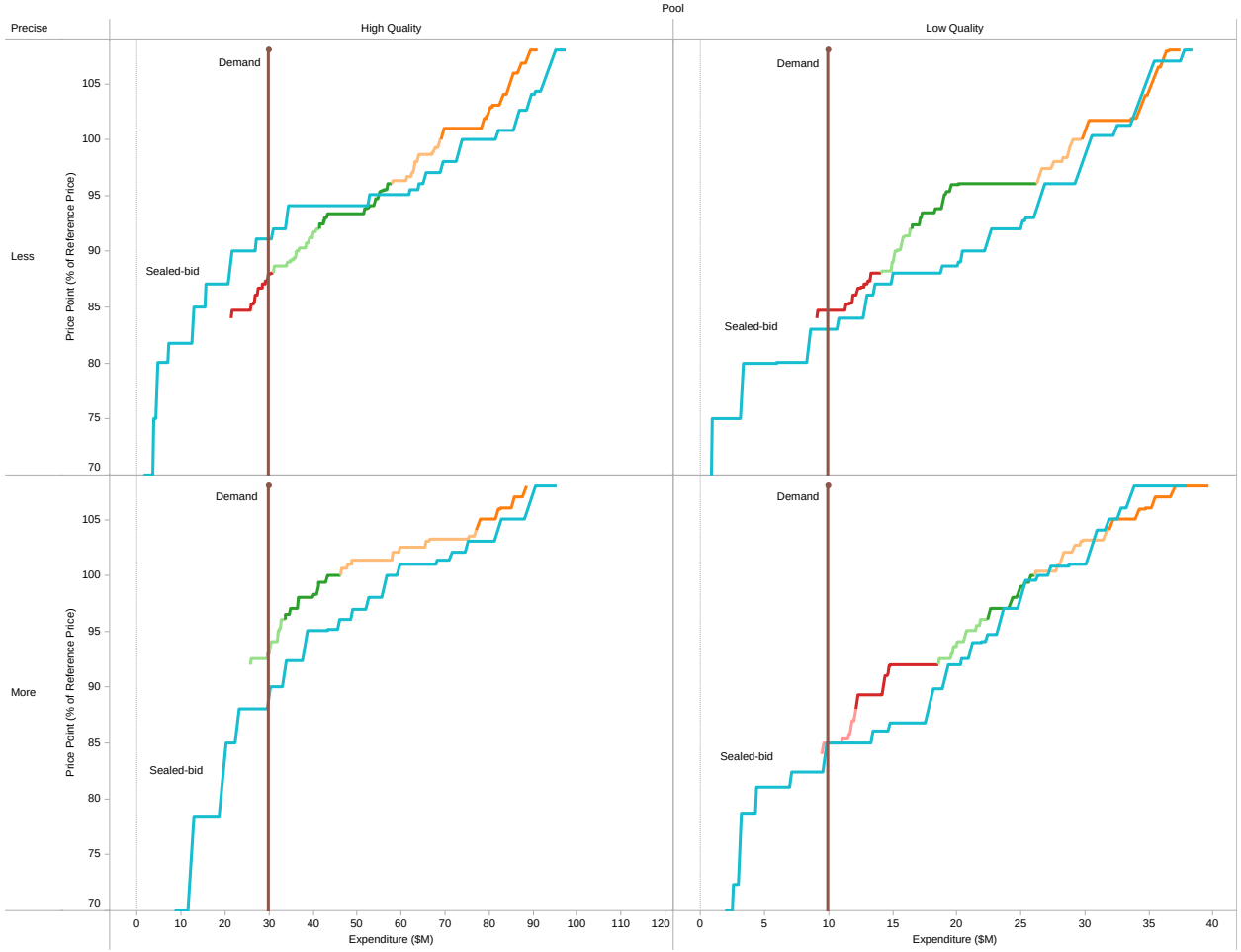


Figure A5.22. Supply and demand by pool and precision (day 2, auction a)

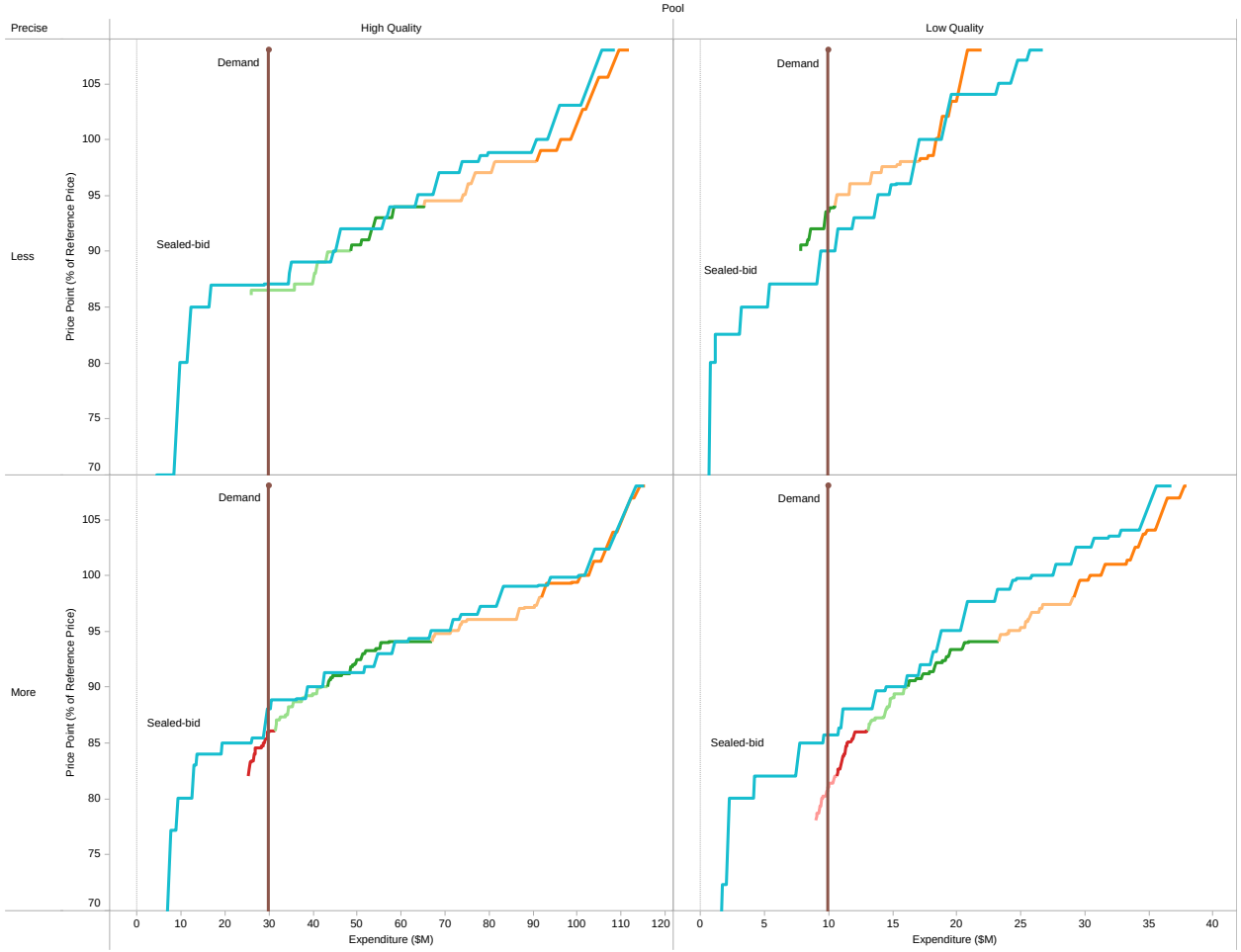


Figure A5.22. Supply and demand by pool and precision (day 2, auction b)

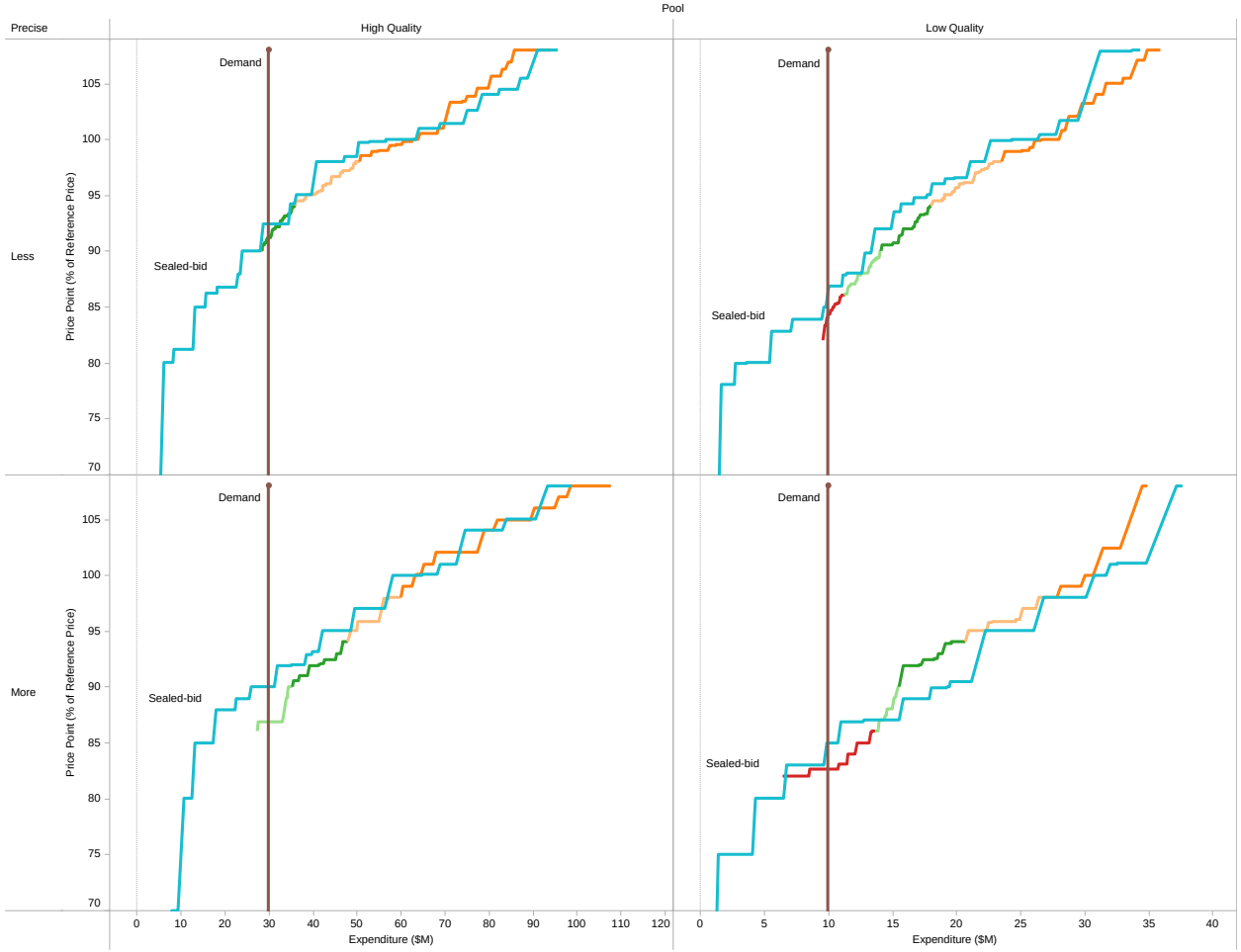


Figure A5.23. Supply and demand by pool and precision (day 3, auction a)

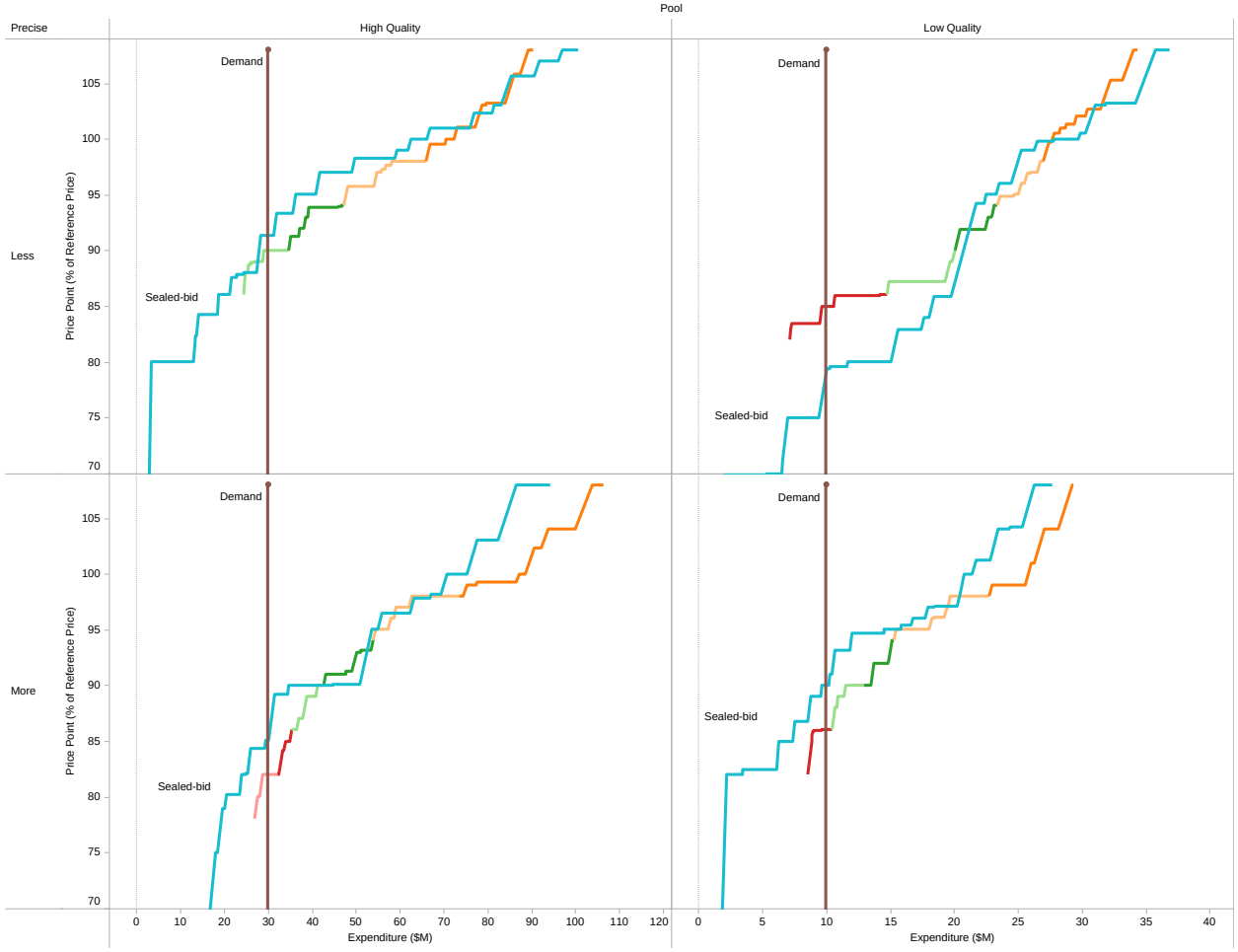


Figure A5.24. Supply and demand by pool and precision (day 3, auction b)

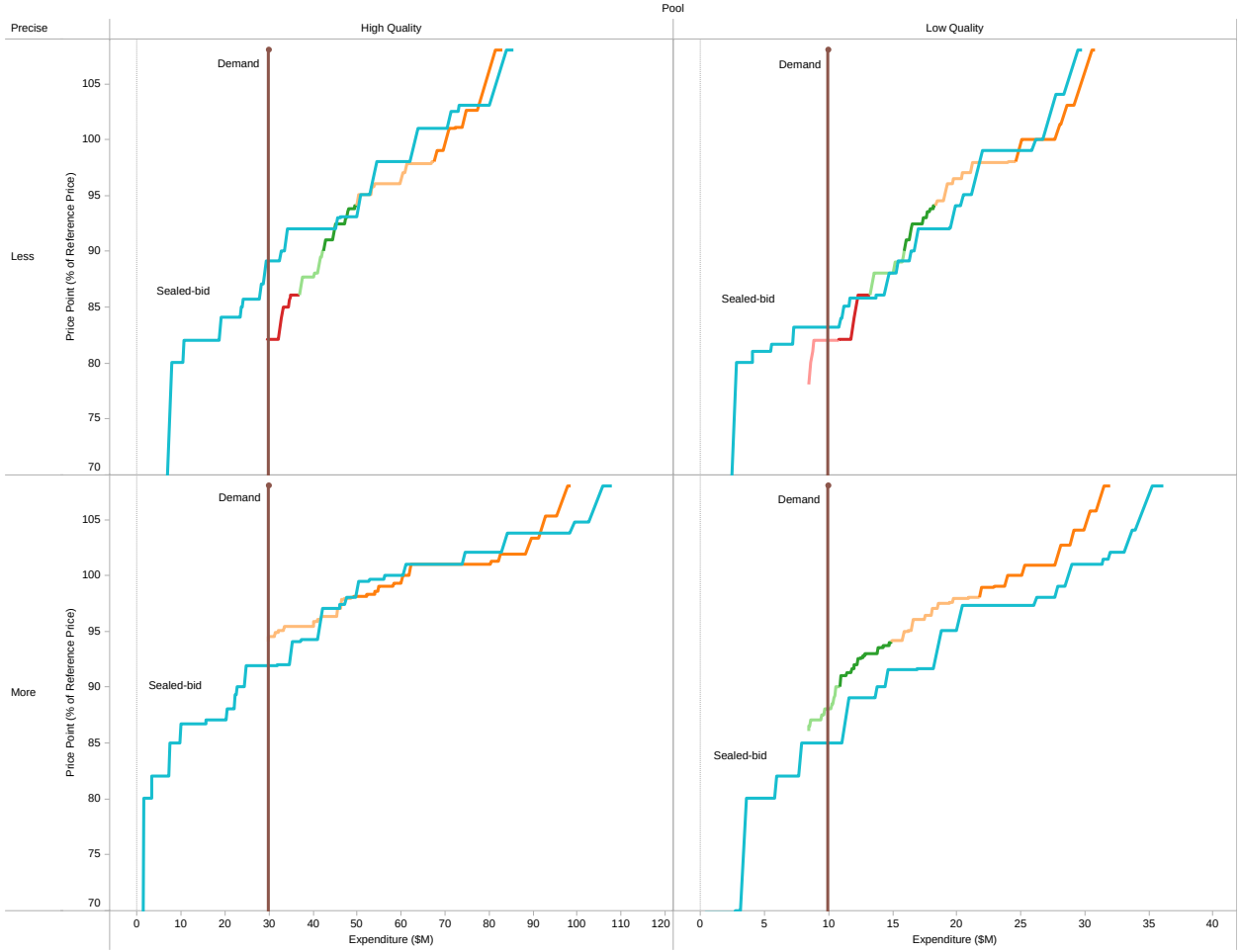


Figure A5.25. Supply and demand by pool and precision (day 4, auction a)

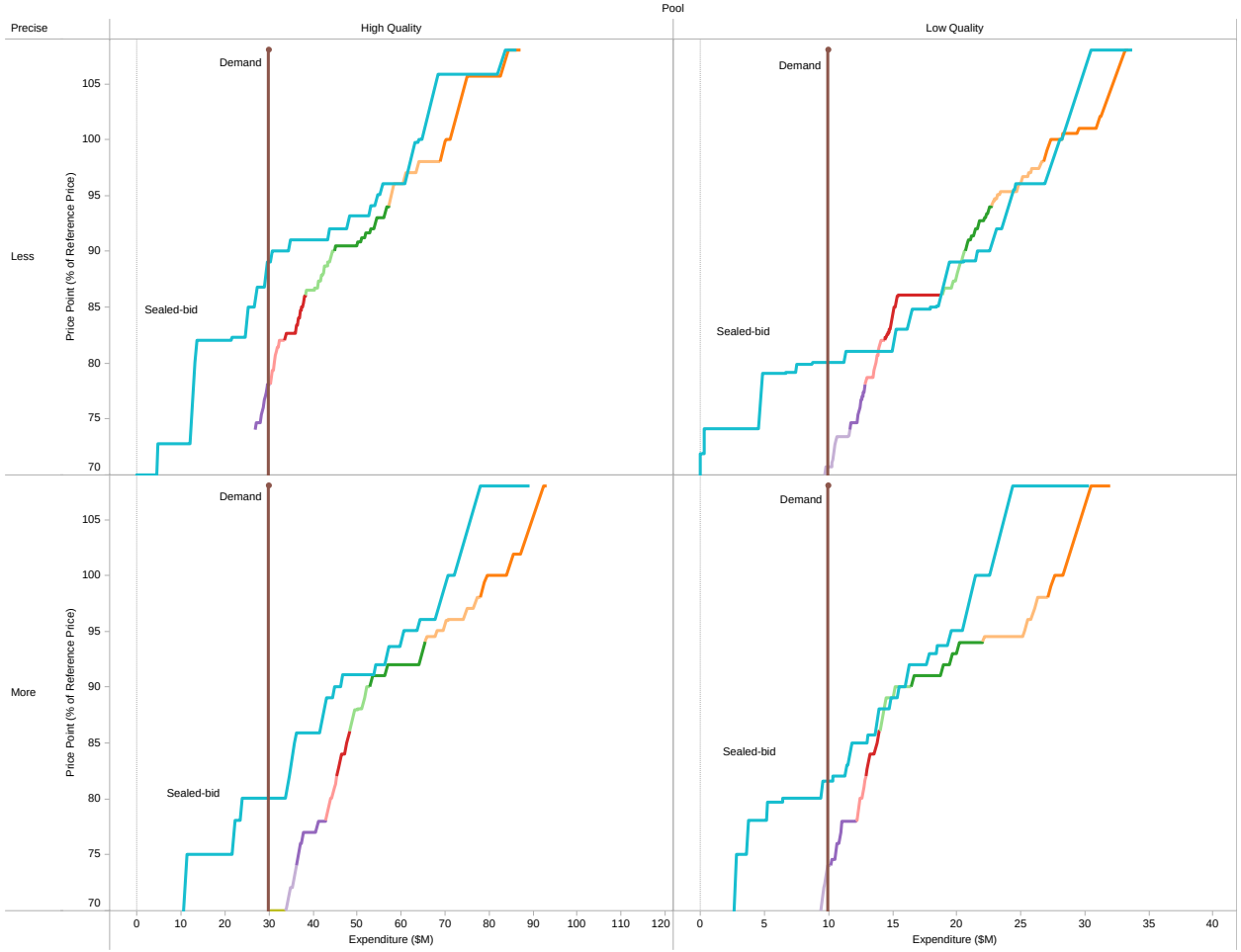
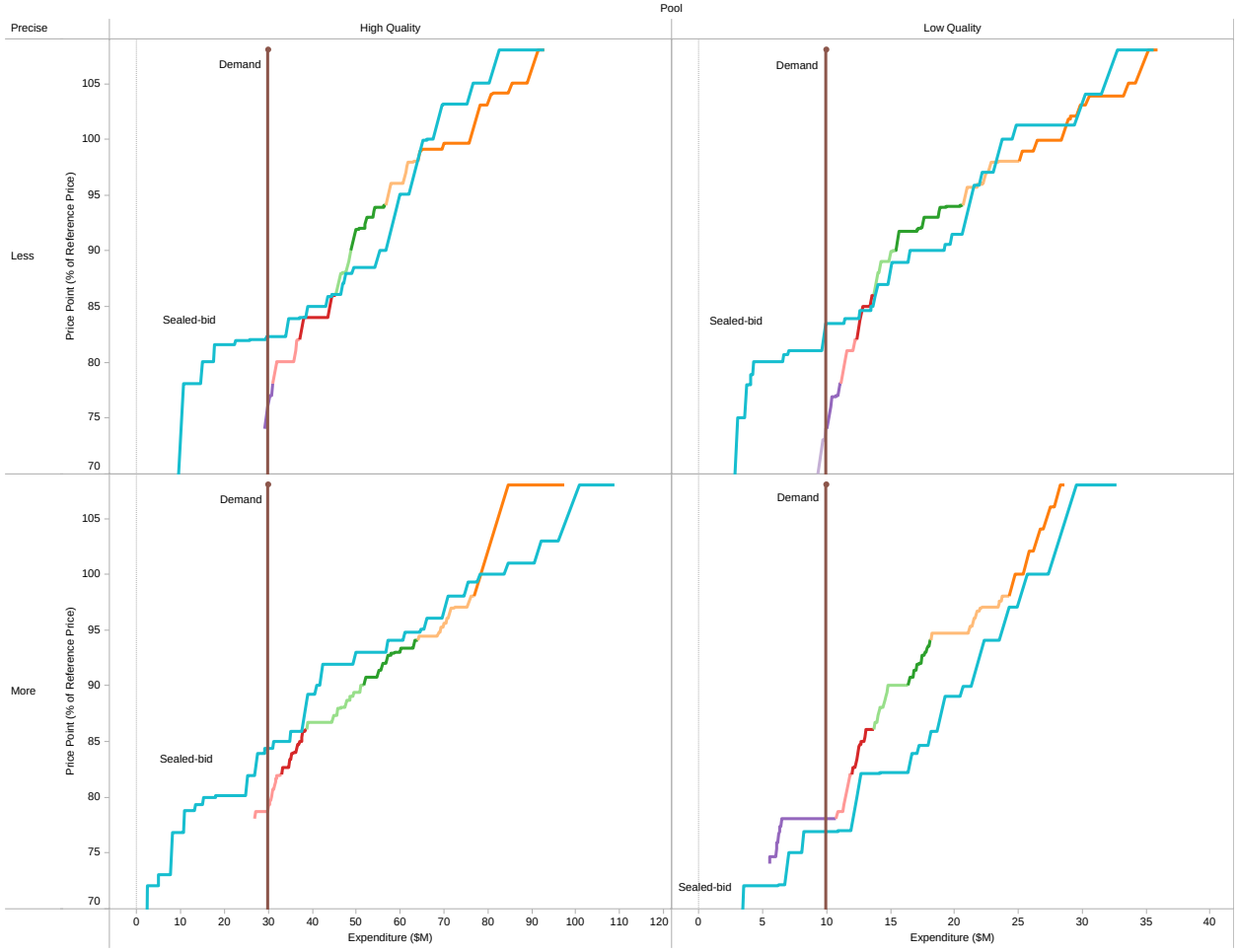


Figure A5.26. Supply and demand by pool and precision (day 4, auction b)



Appendix 6

Figures from Experiment 3.1: A Common Value Auction without Liquidity Needs

Figure A6.1. Supply and demand (day 6, auction 1a)

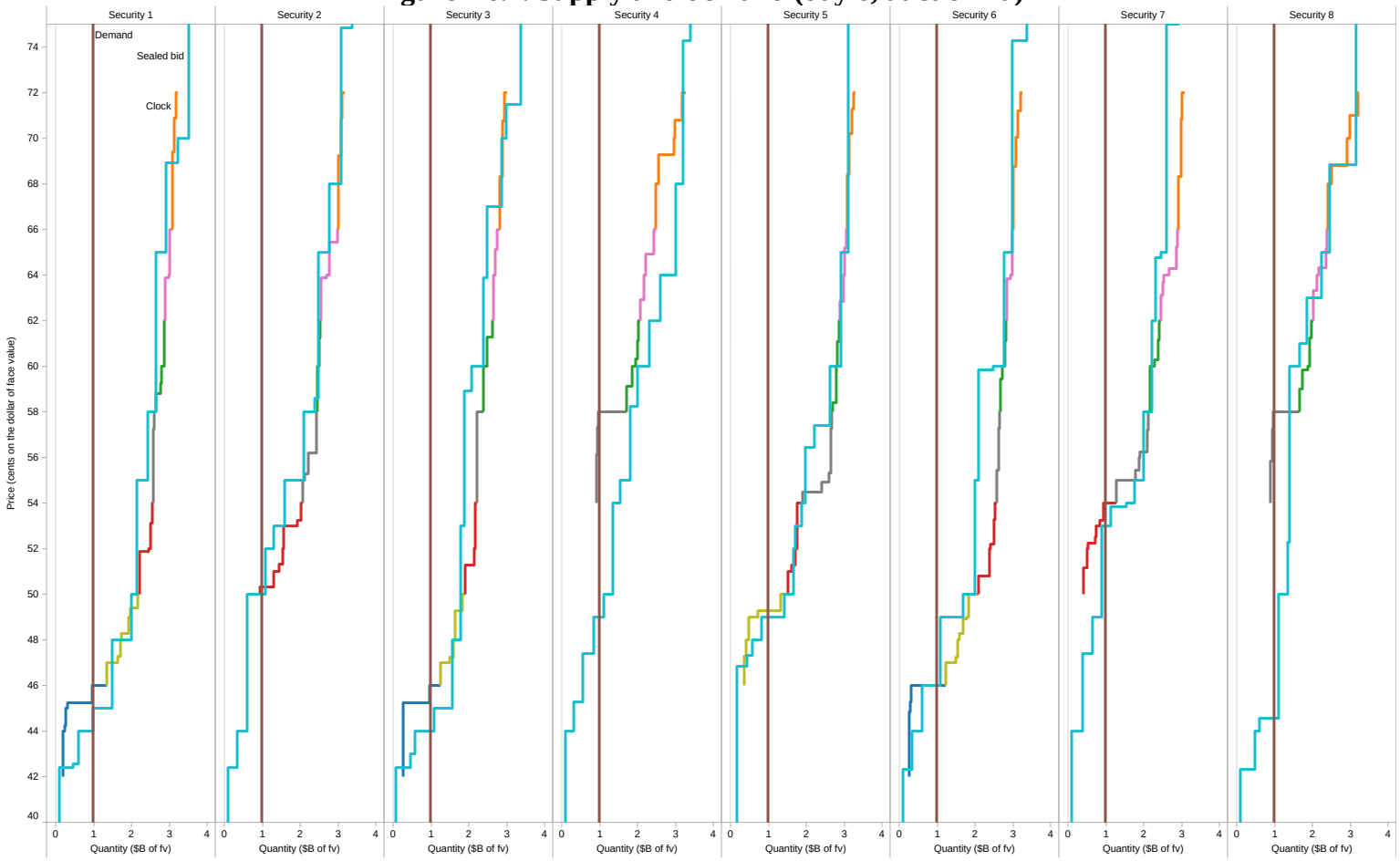


Figure A6.2. Supply and demand (day 6, auction 1b)

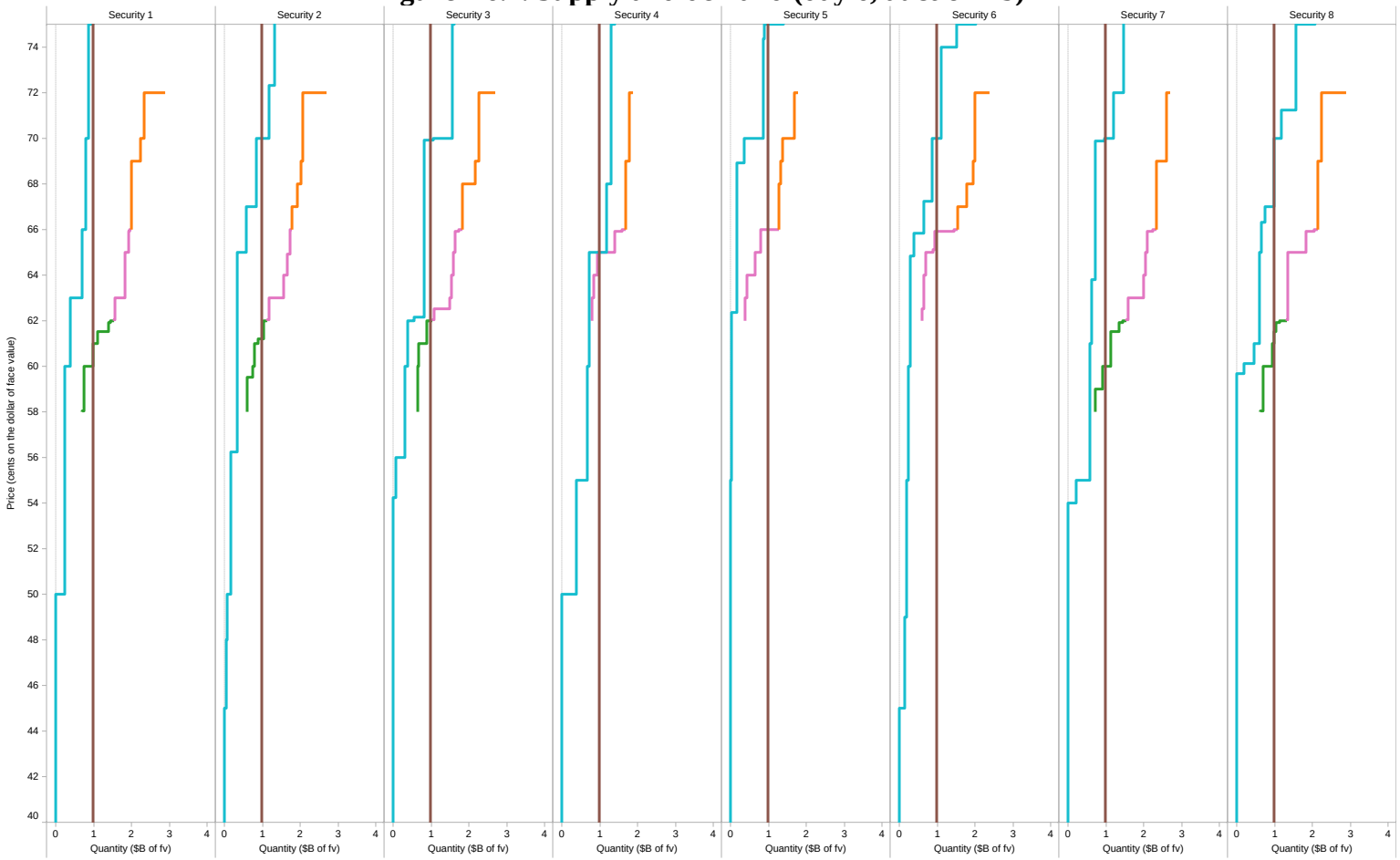


Figure A6.3. Supply and demand (day 6, auction 1c)

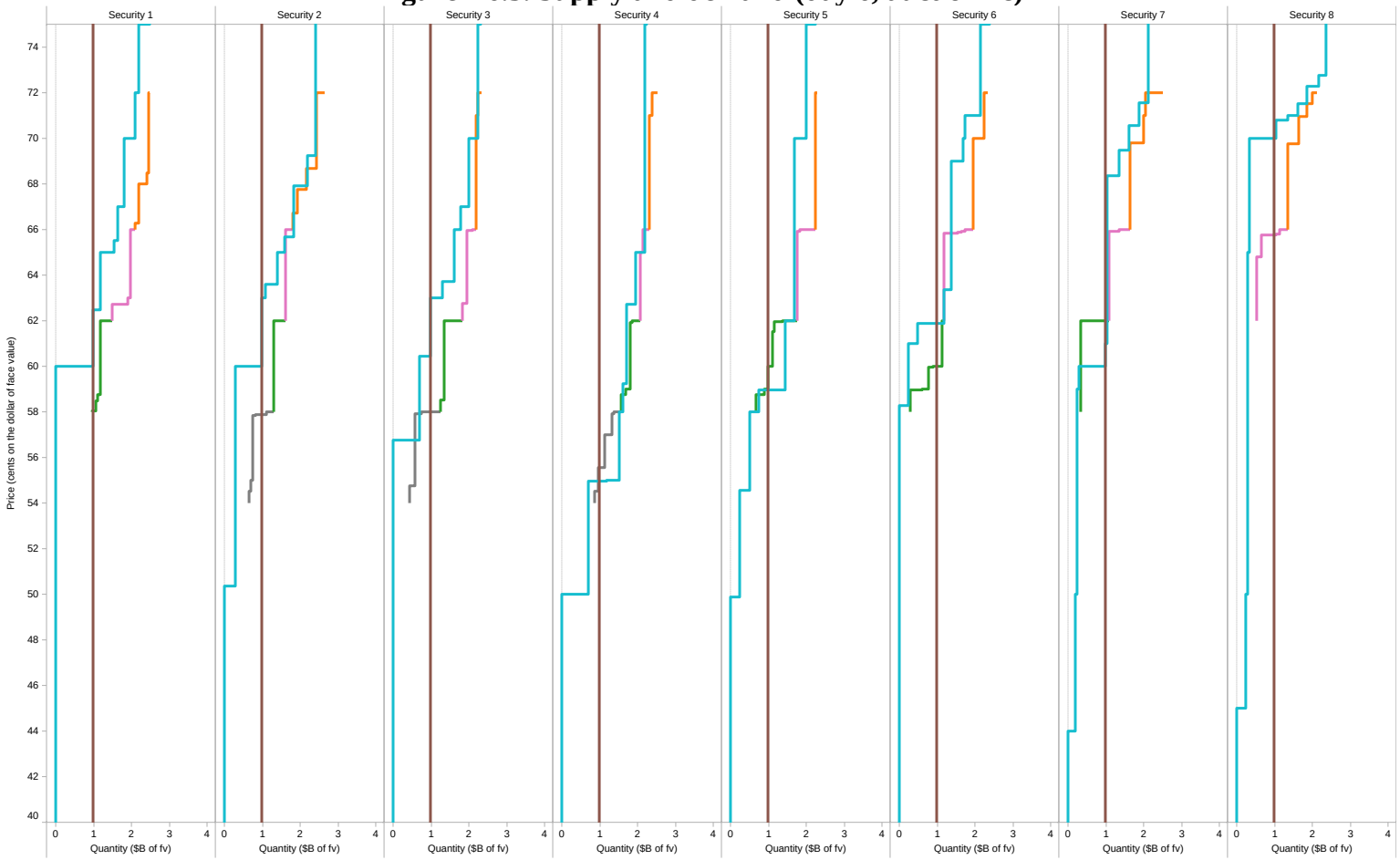


Figure A6.4. Supply and demand (day 6, auction 1d)

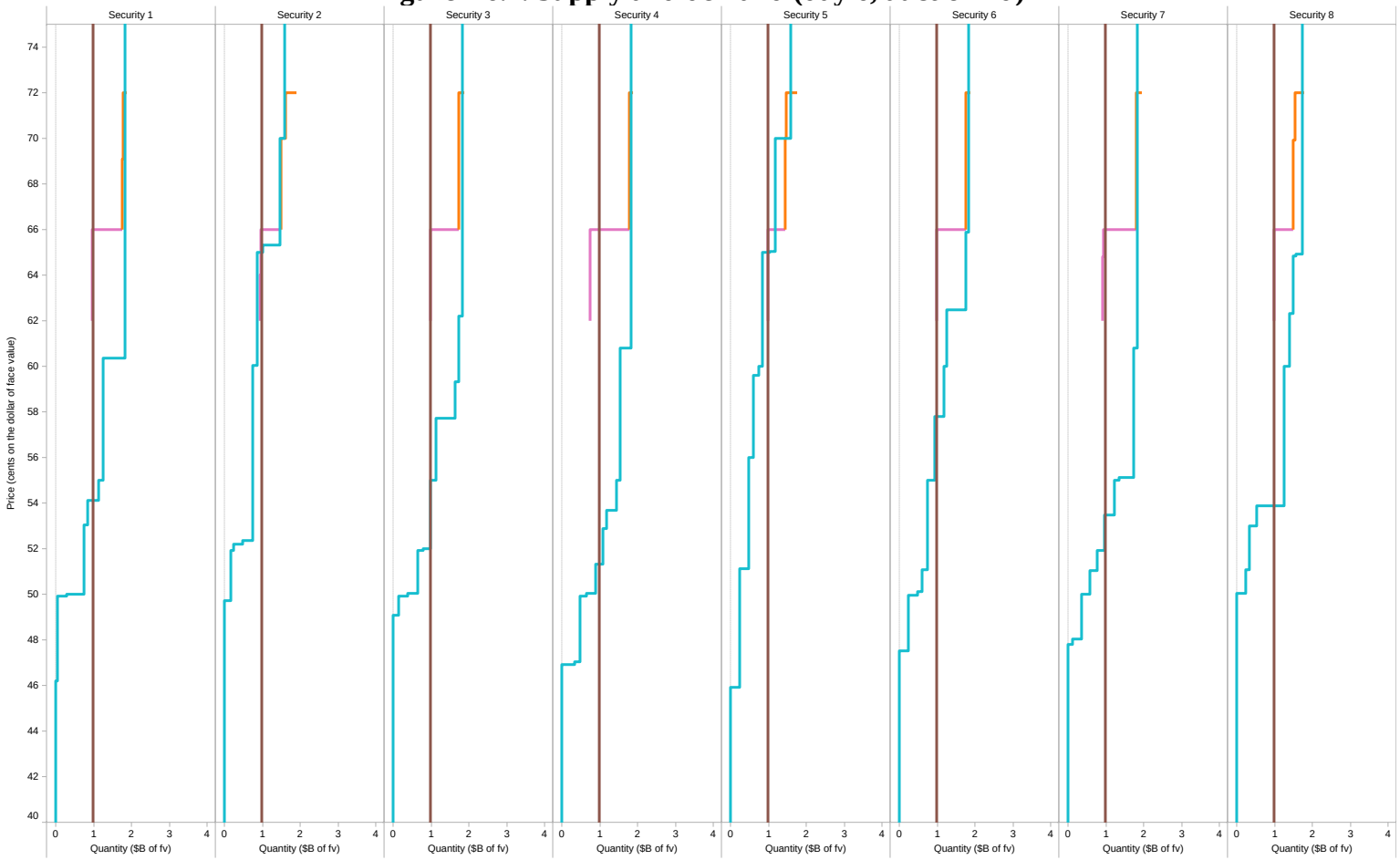


Figure A6.5. Supply and demand (day 6, auction 2a)

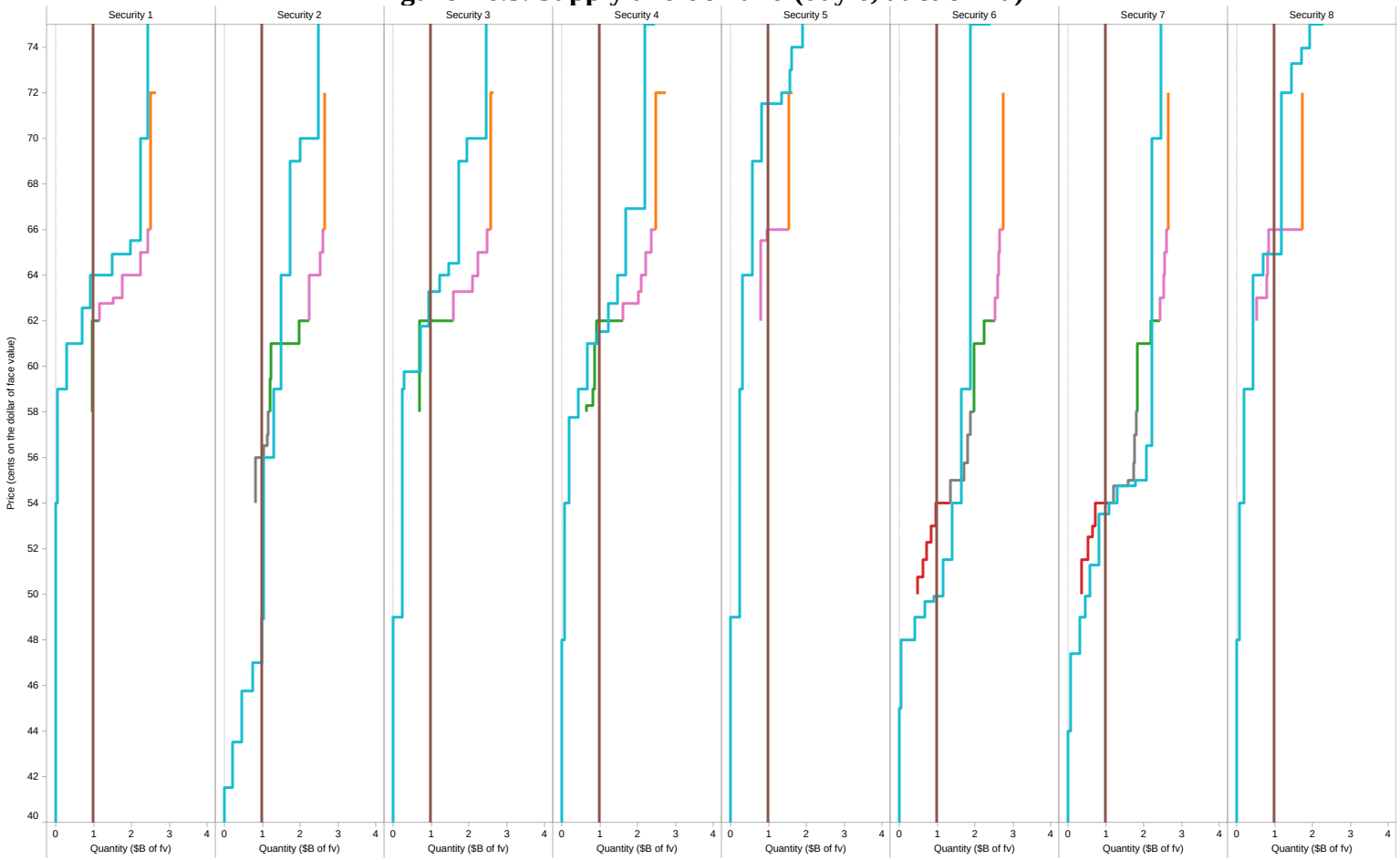


Figure A6.6. Supply and demand (day 6, auction 2b)

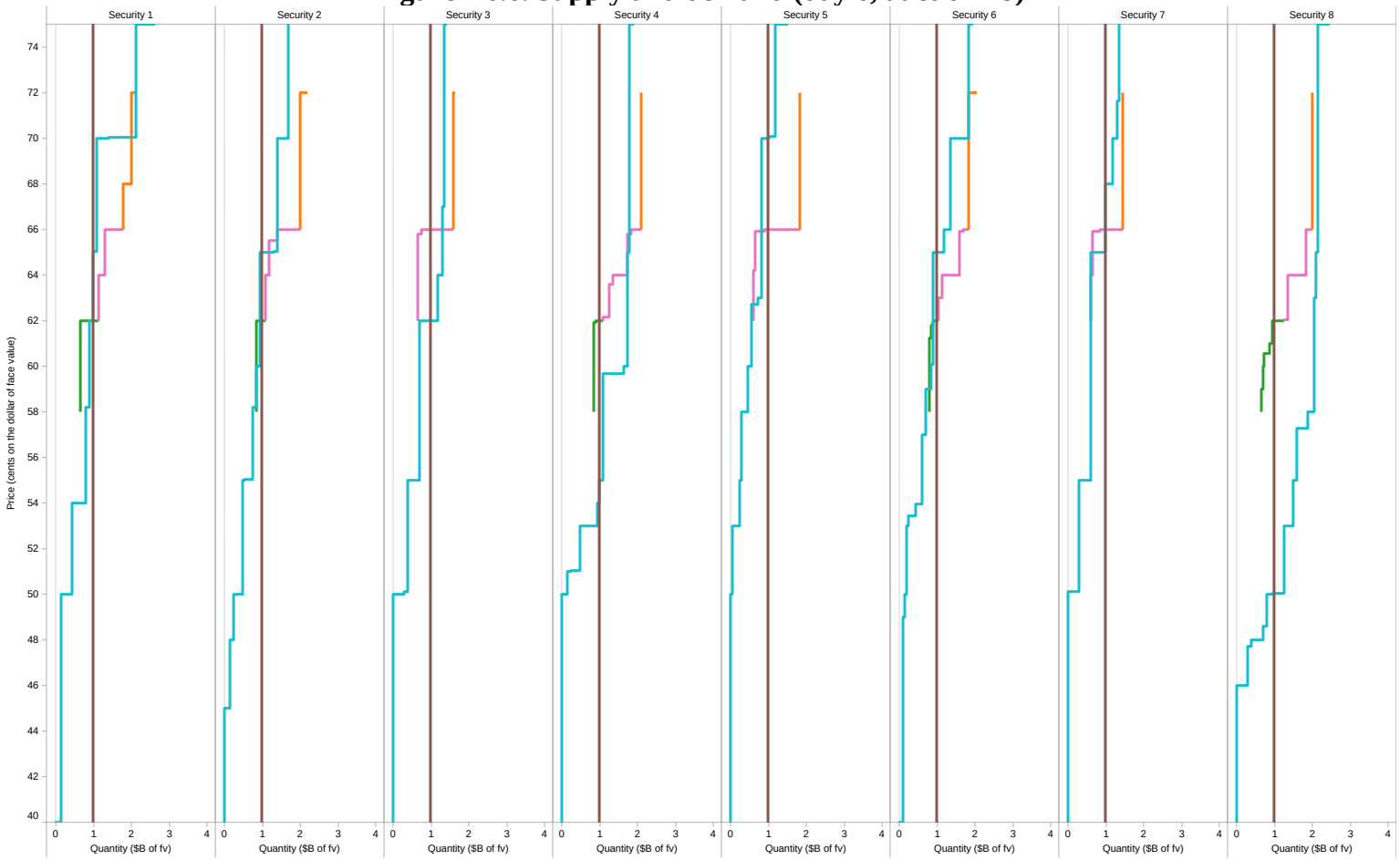


Figure A6.7. Supply and demand (day 6, auction 2c)

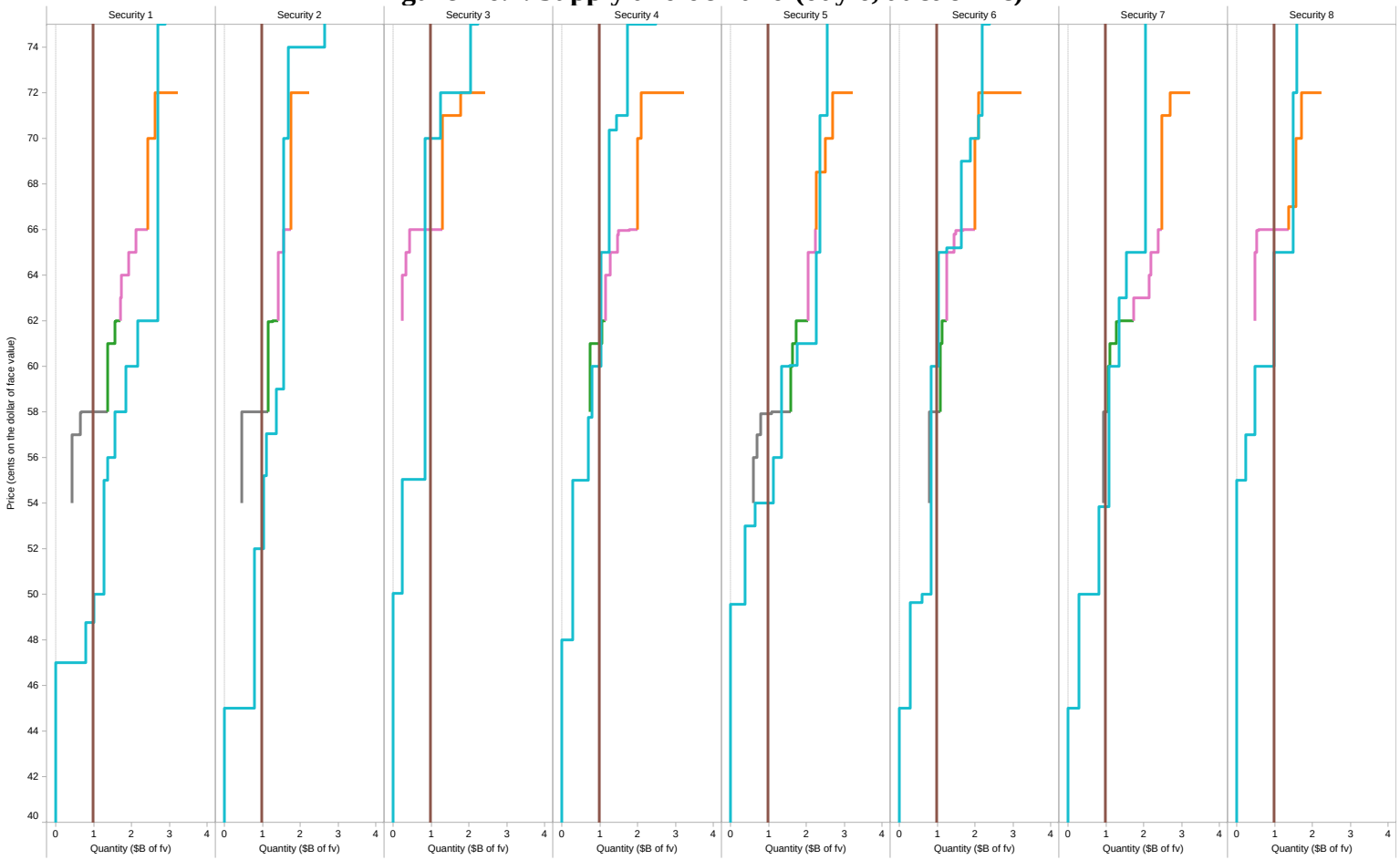


Figure A6.8. Supply and demand (day 6, auction 2d)

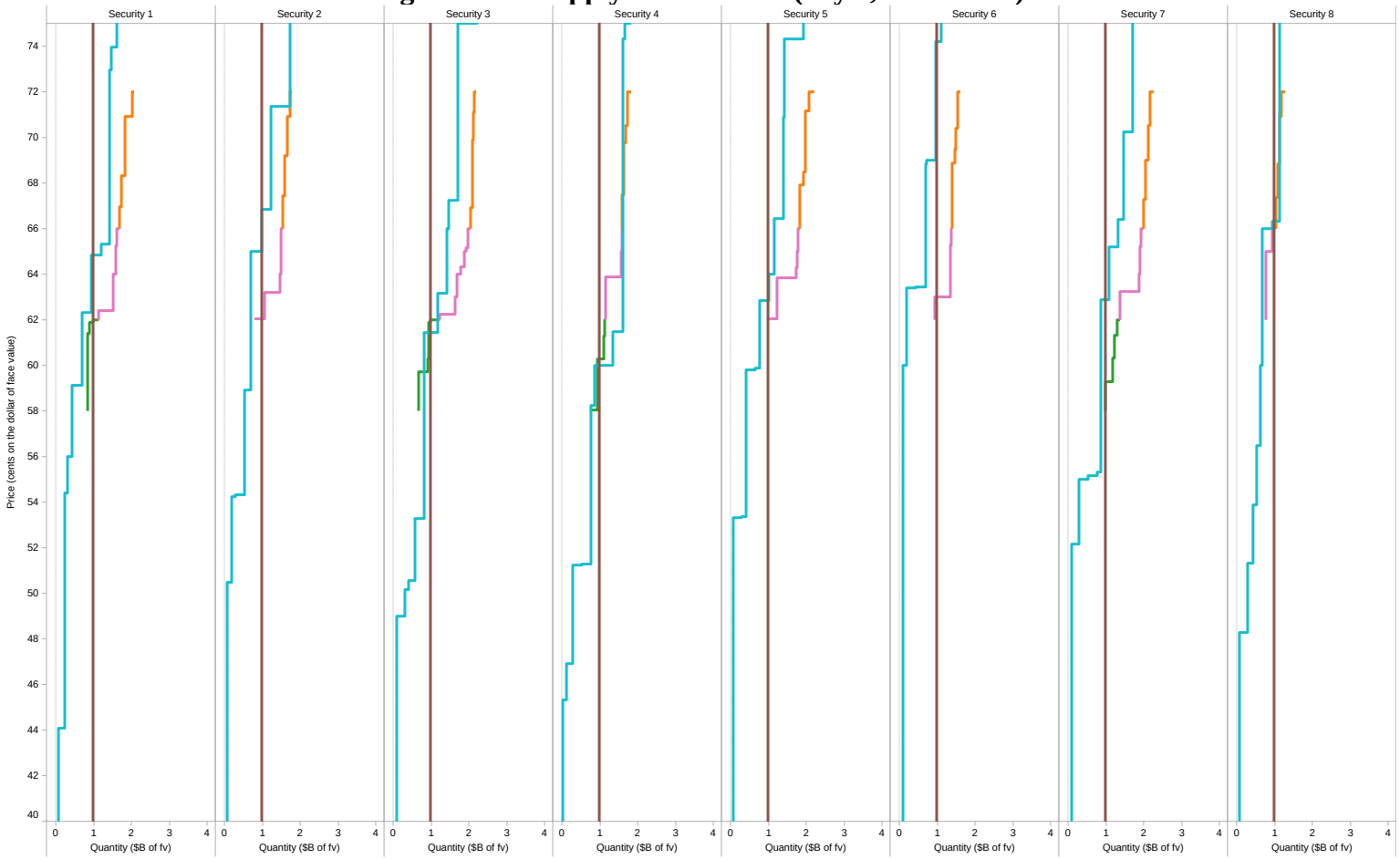


Figure A6.9. Supply and demand (day 8, auction 1a)

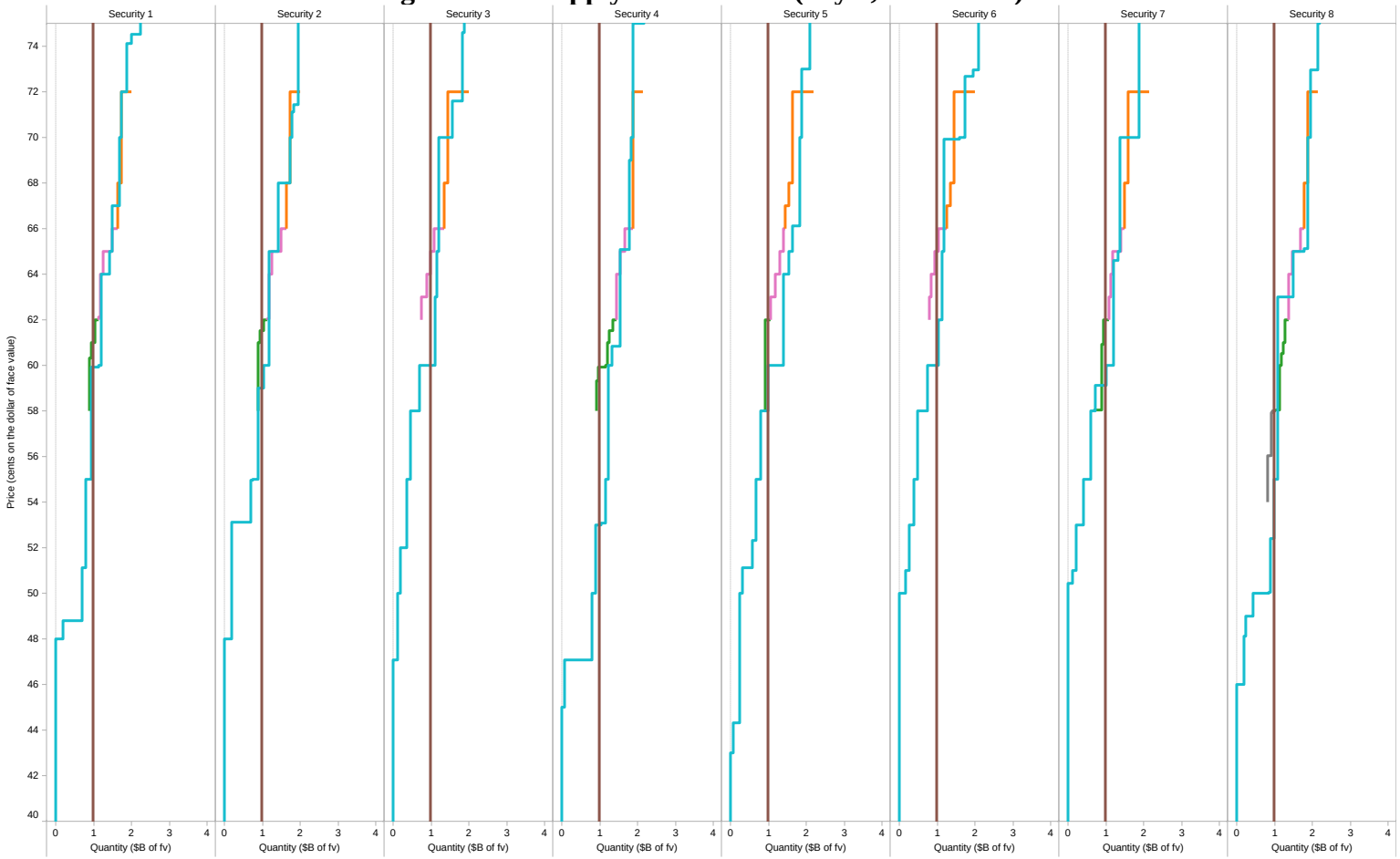


Figure A6.10. Supply and demand (day 8, auction 1b)

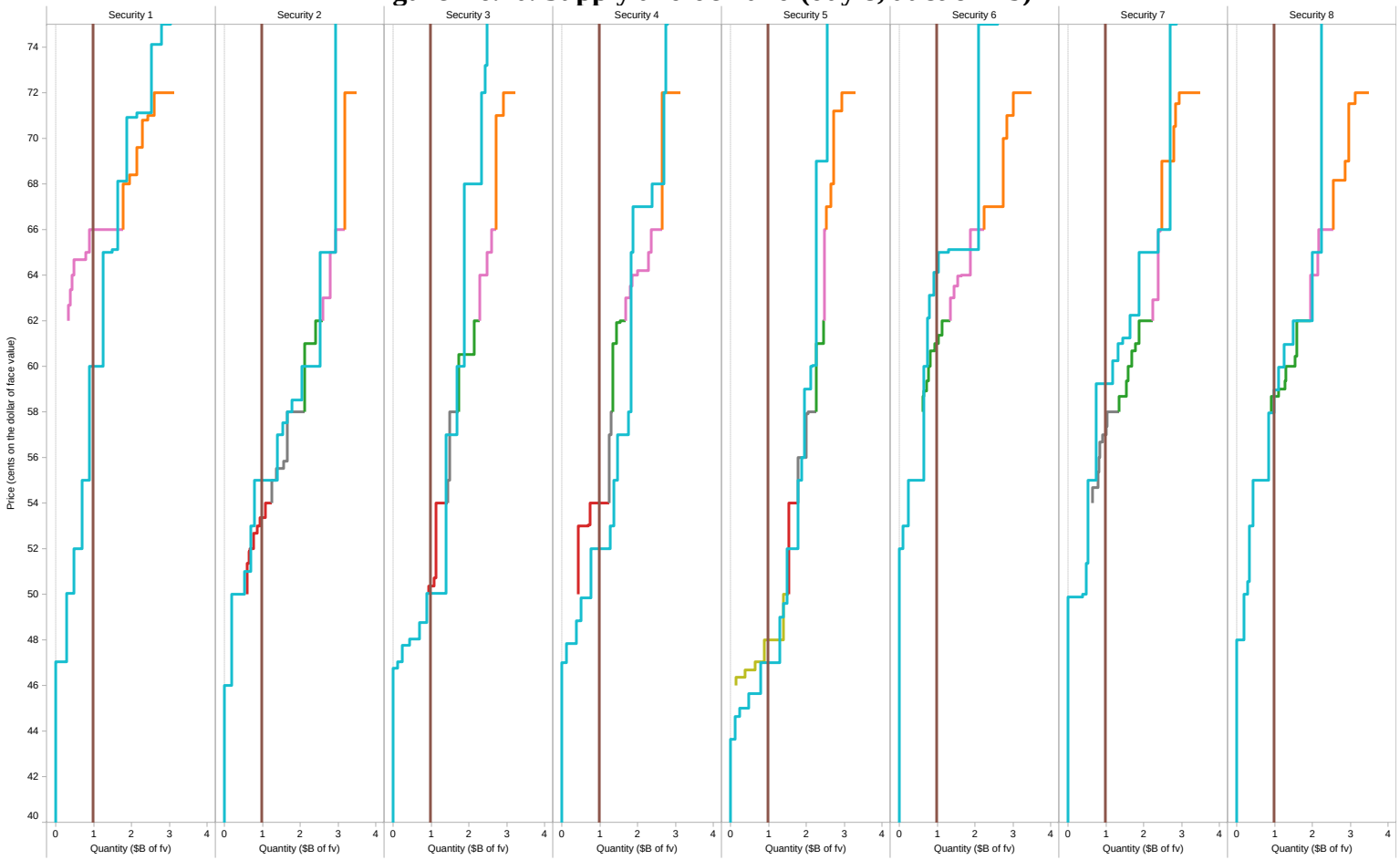


Figure A6.11. Supply and demand (day 8, auction 1c)

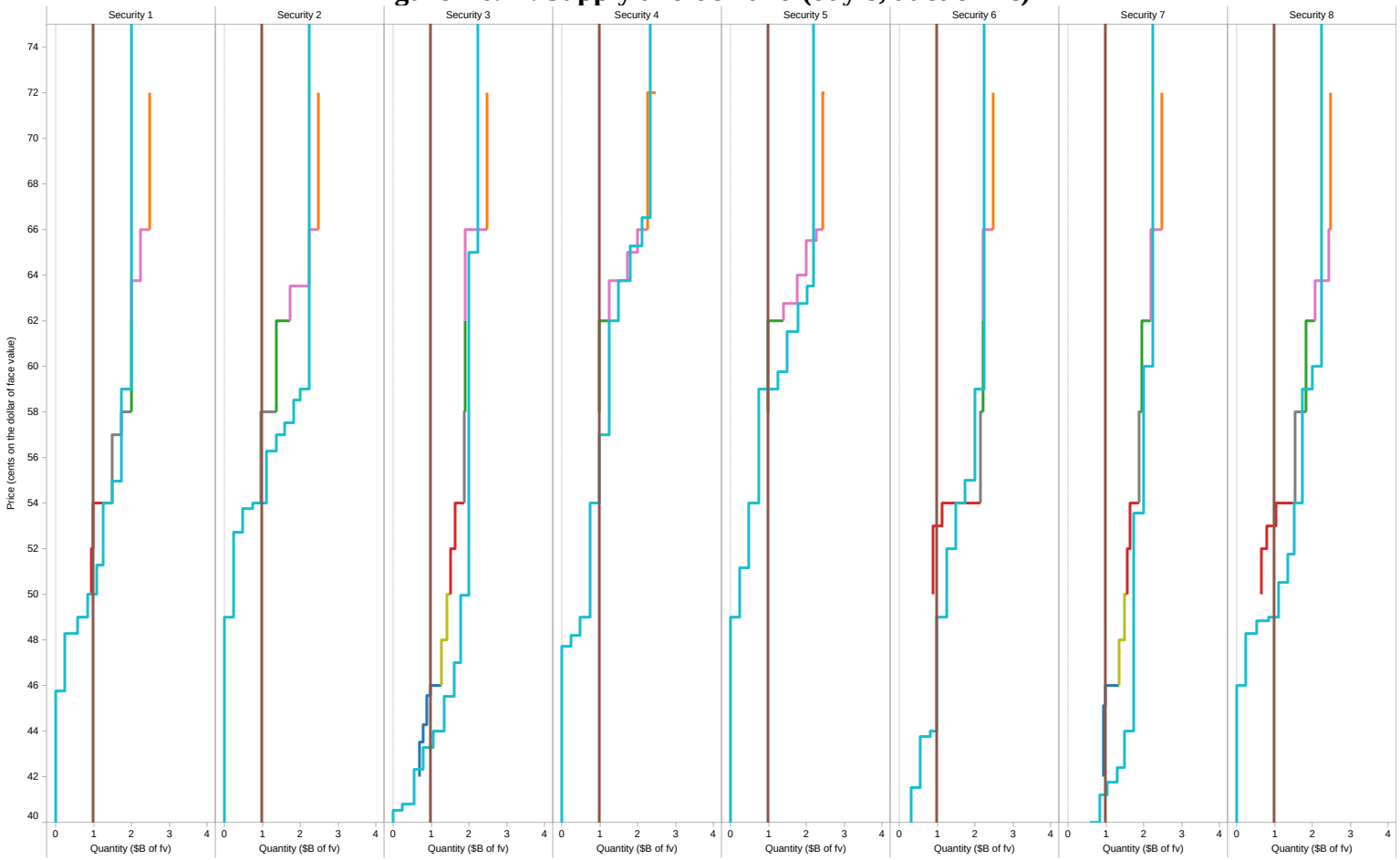


Figure A6.12. Supply and demand (day 8, auction 1d)

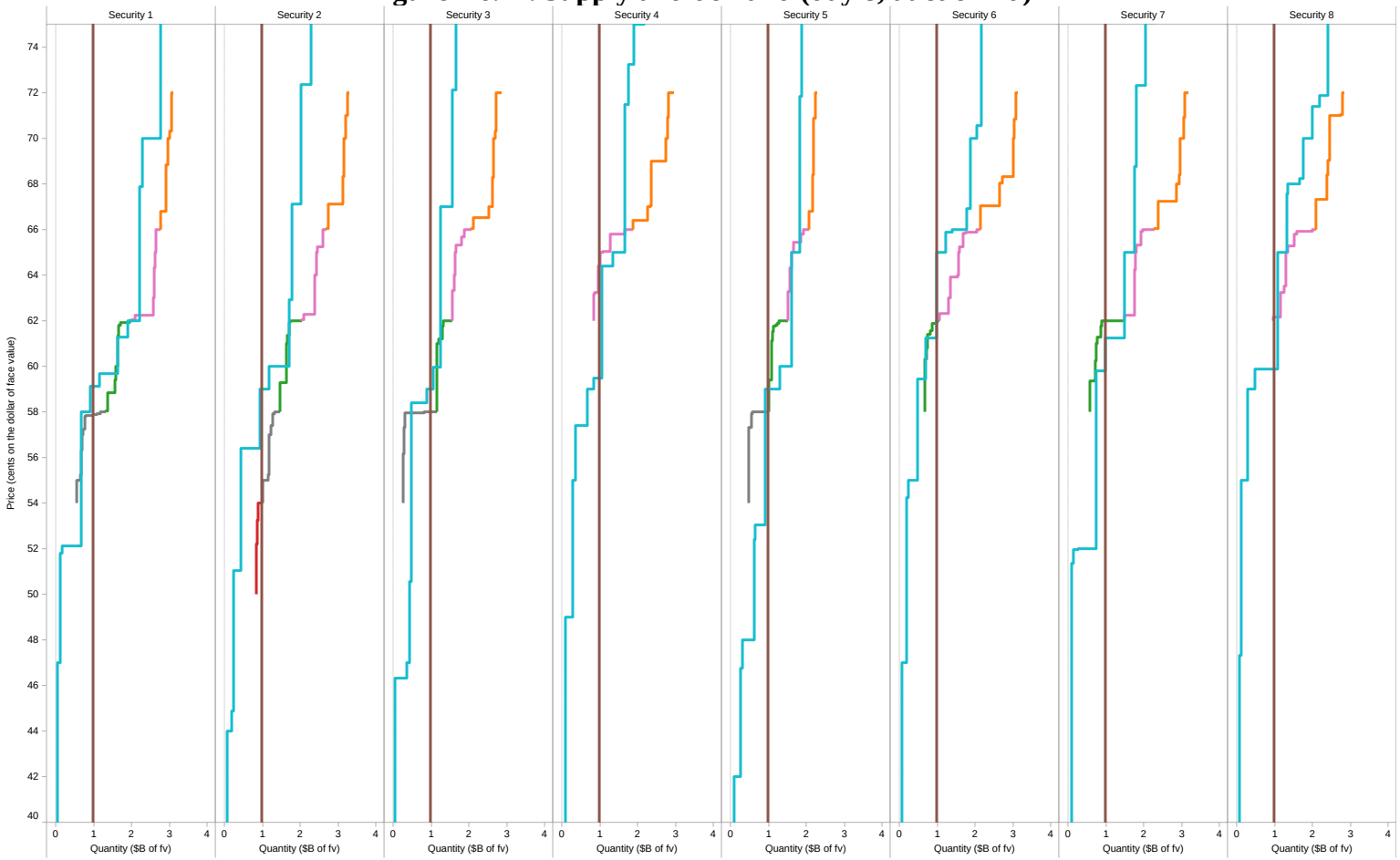


Figure A6.13. Supply and demand (day 8, auction 2a)

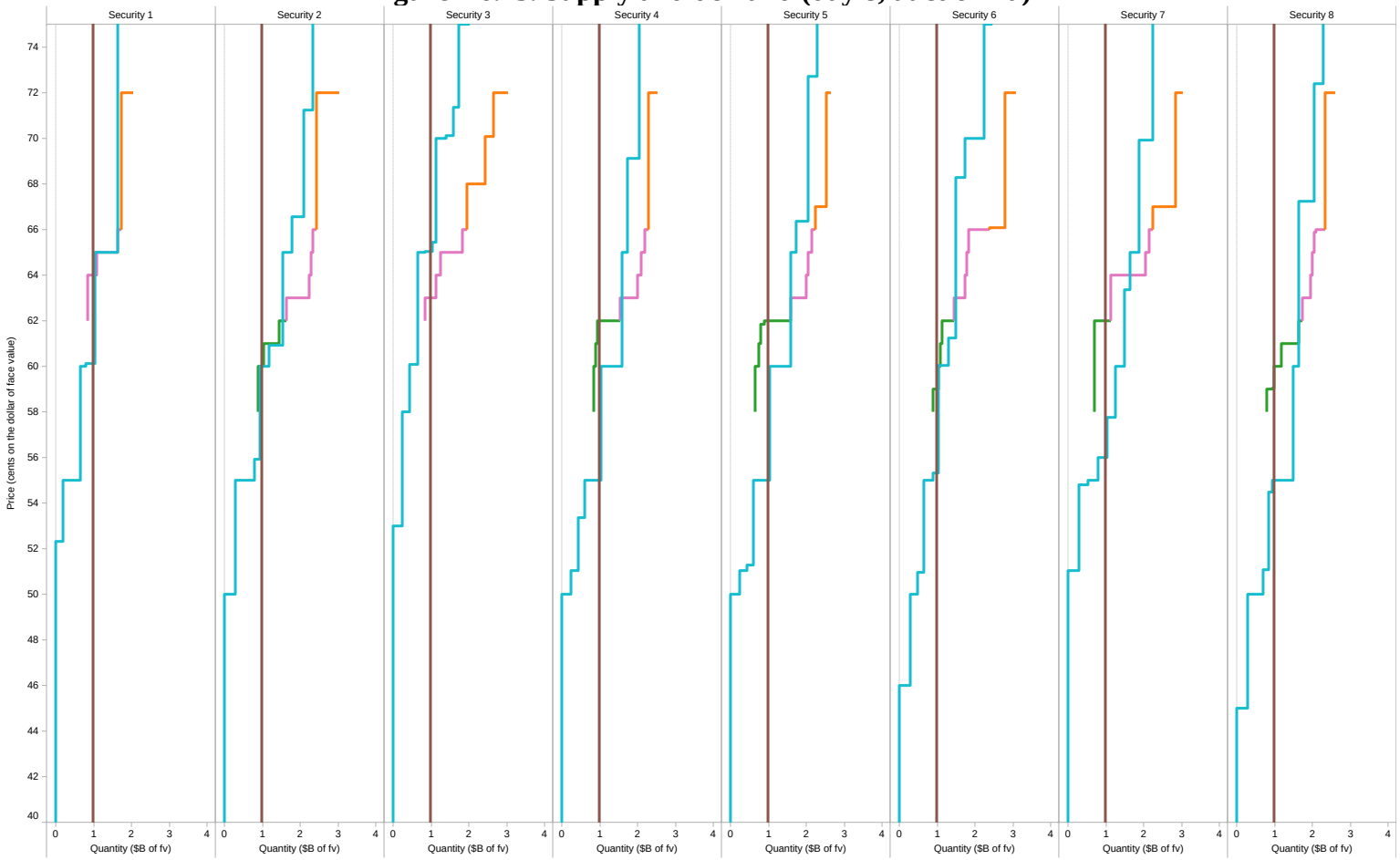


Figure A6.14. Supply and demand (day 8, auction 2b)

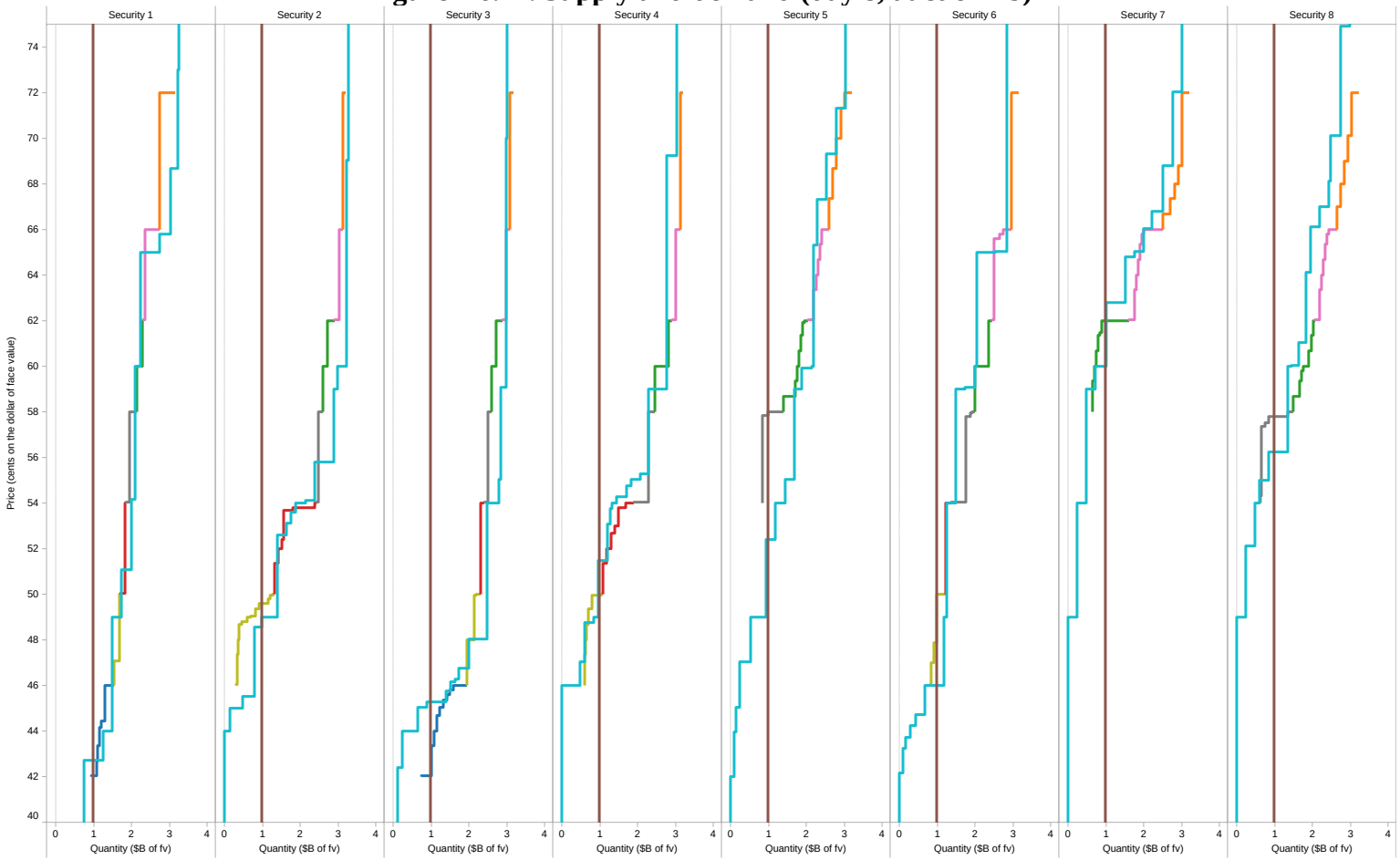


Figure A6.15. Supply and demand (day 8, auction 2c)

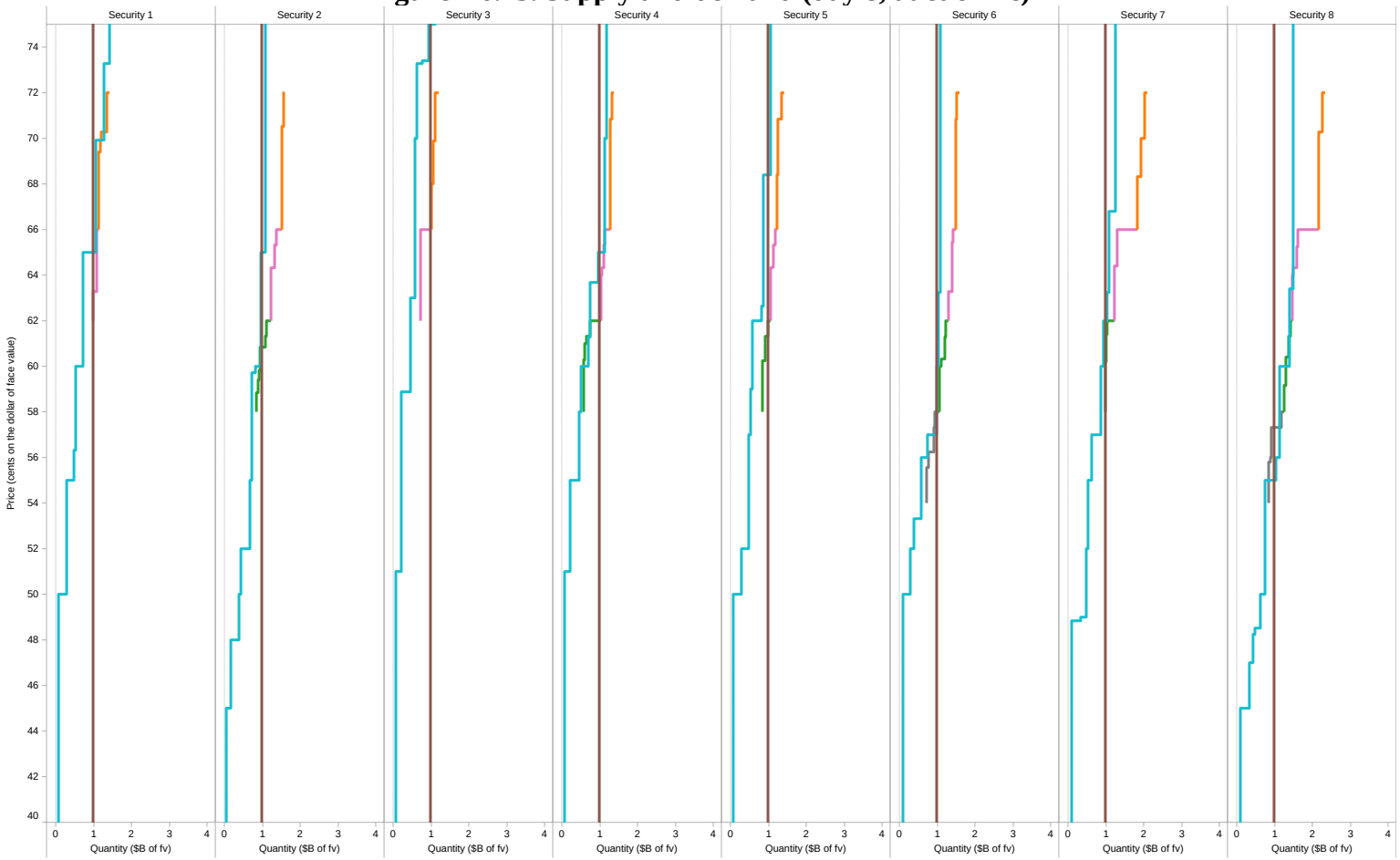


Figure A6.16. Supply and demand (day 8, auction 2d)

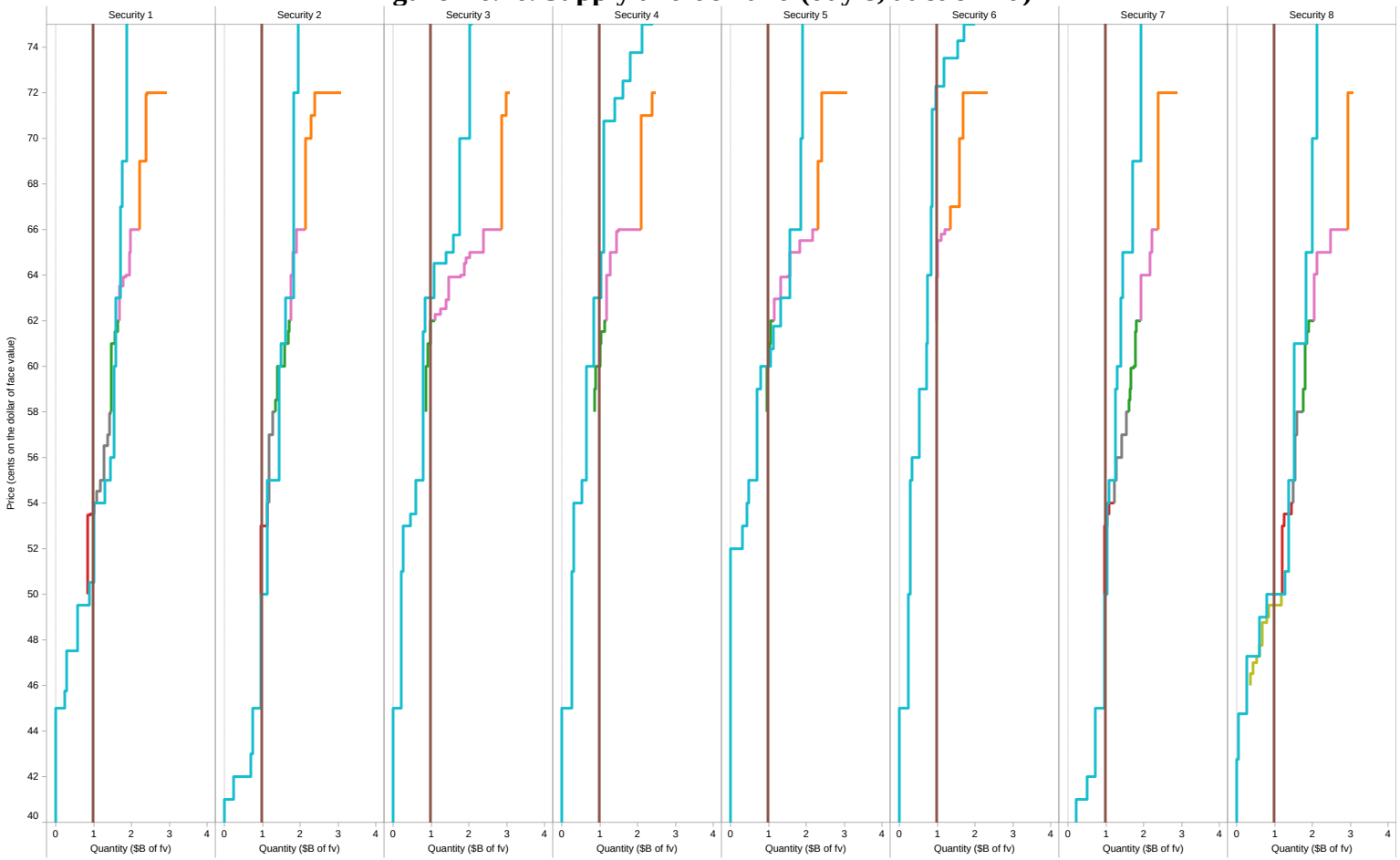
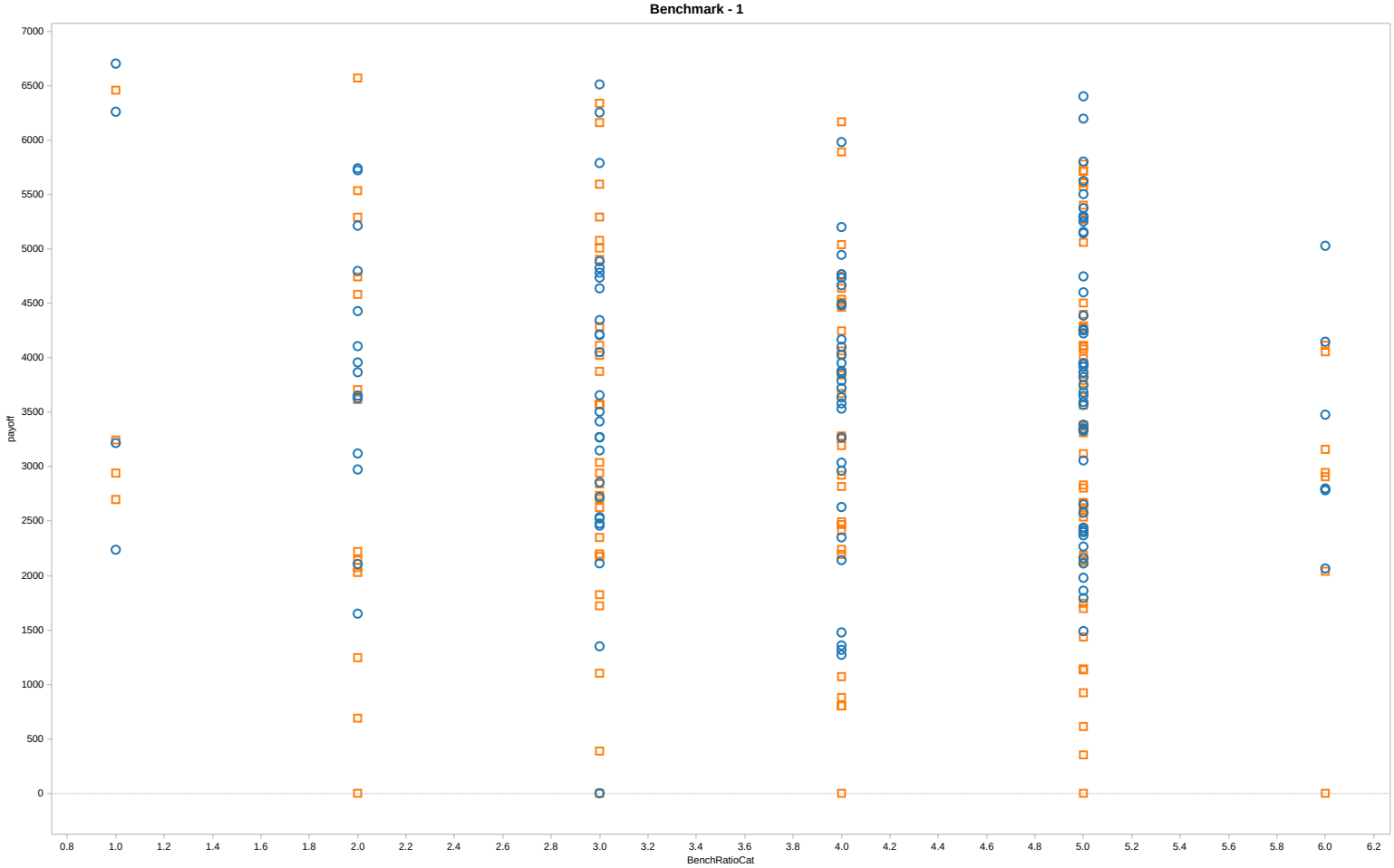


Figure A6.17. Payoff as a function of the benchmark ratio

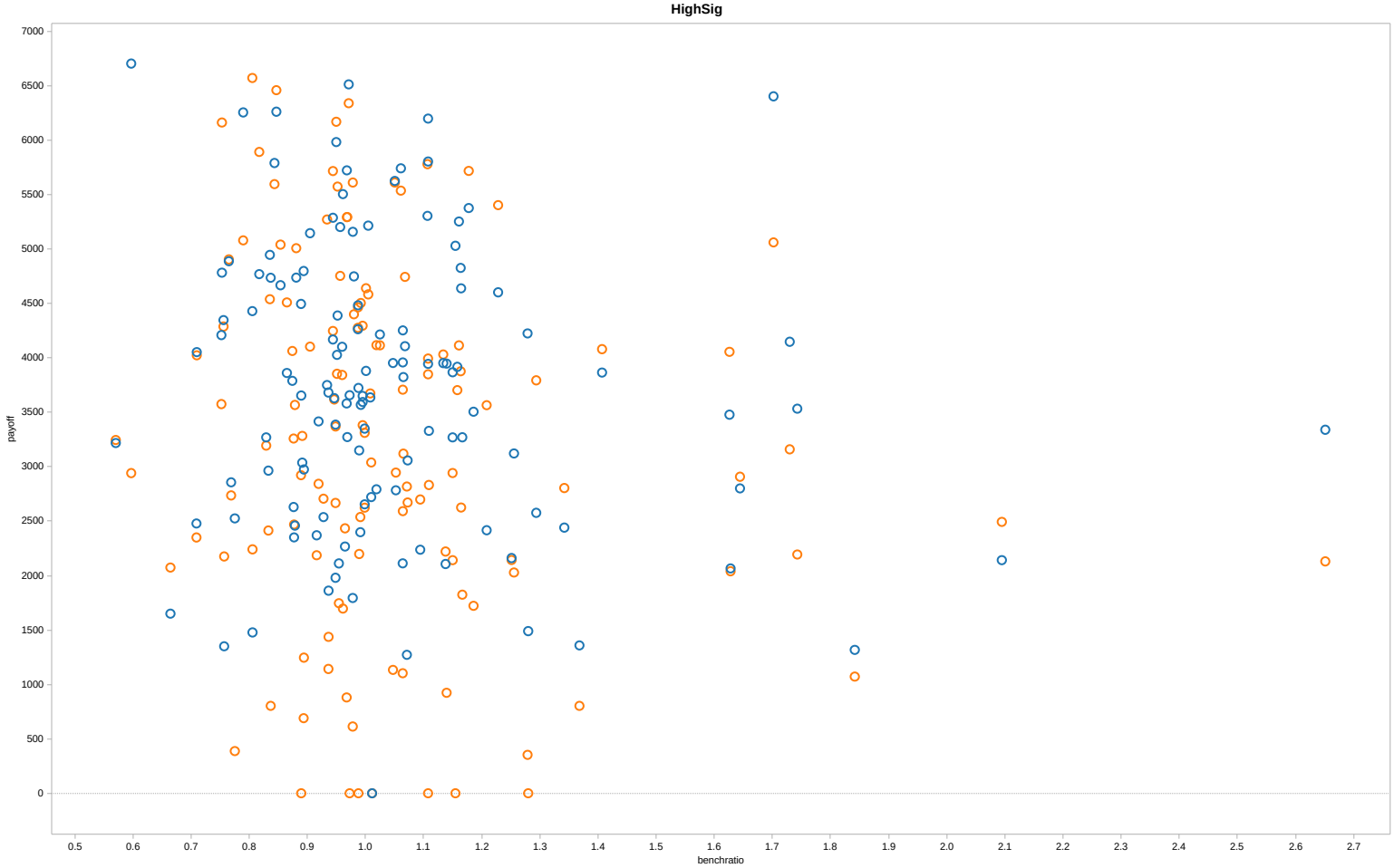


BenchRatioCat vs. payoff for 1. Color shows details about Clock. Shape shows details about Clock. The data is filtered on Day, which ranges from 1 to 4. The view is filtered on bratio1rank, which keeps 1, 2, 3 and 4.

Clock

- clock
- sbid

Figure A6.18. Payoff as a function of benchmark ratio for high signals

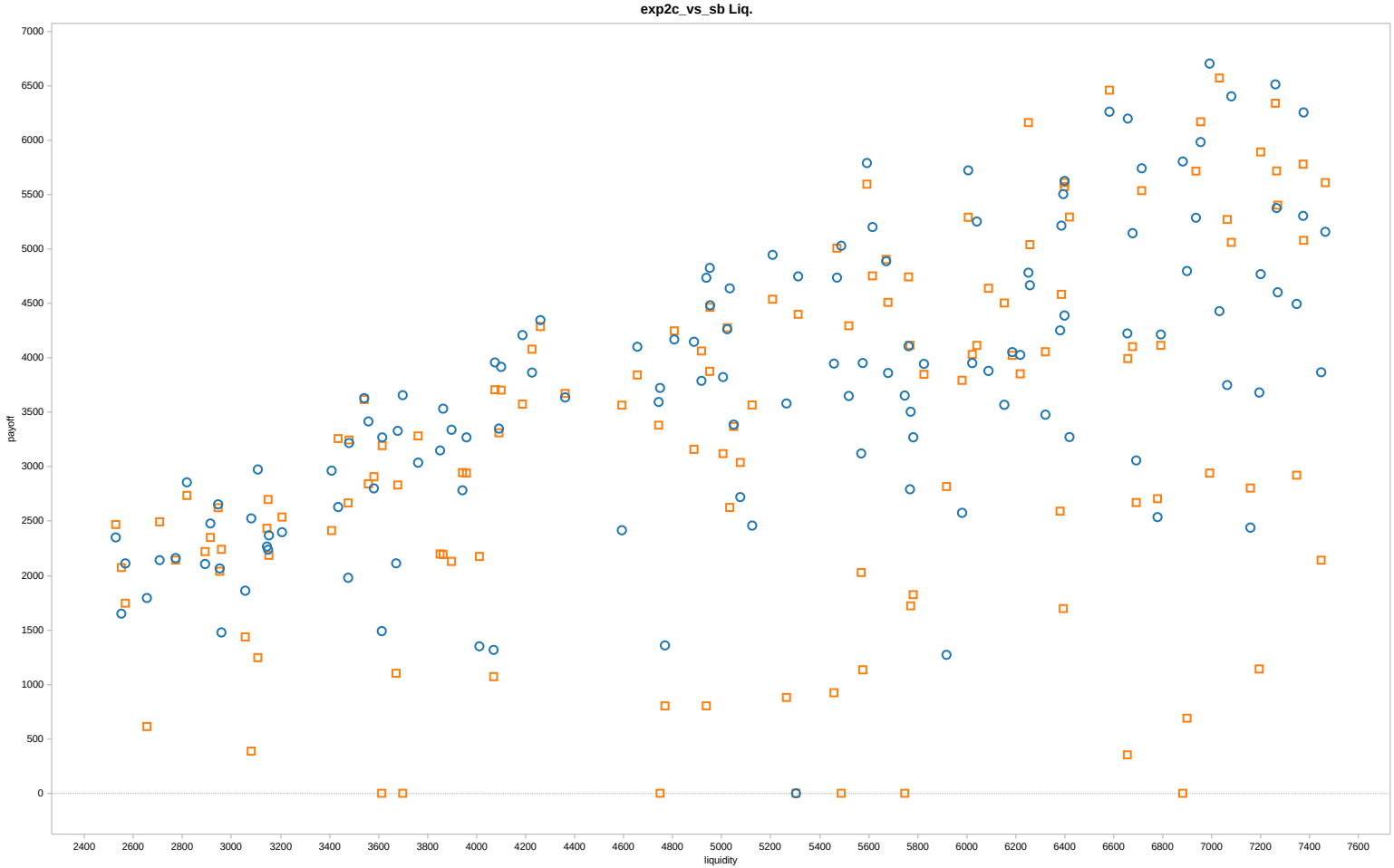


Benchratio vs. payoff. Color shows details about Clock. The data is filtered on Day and numsignals. The Day filter ranges from 1 to 4. The numsignals filter ranges from 4 to 4.

Clock

- clock
- sbid

Figure A6.19. Payoff as a function of liquidity

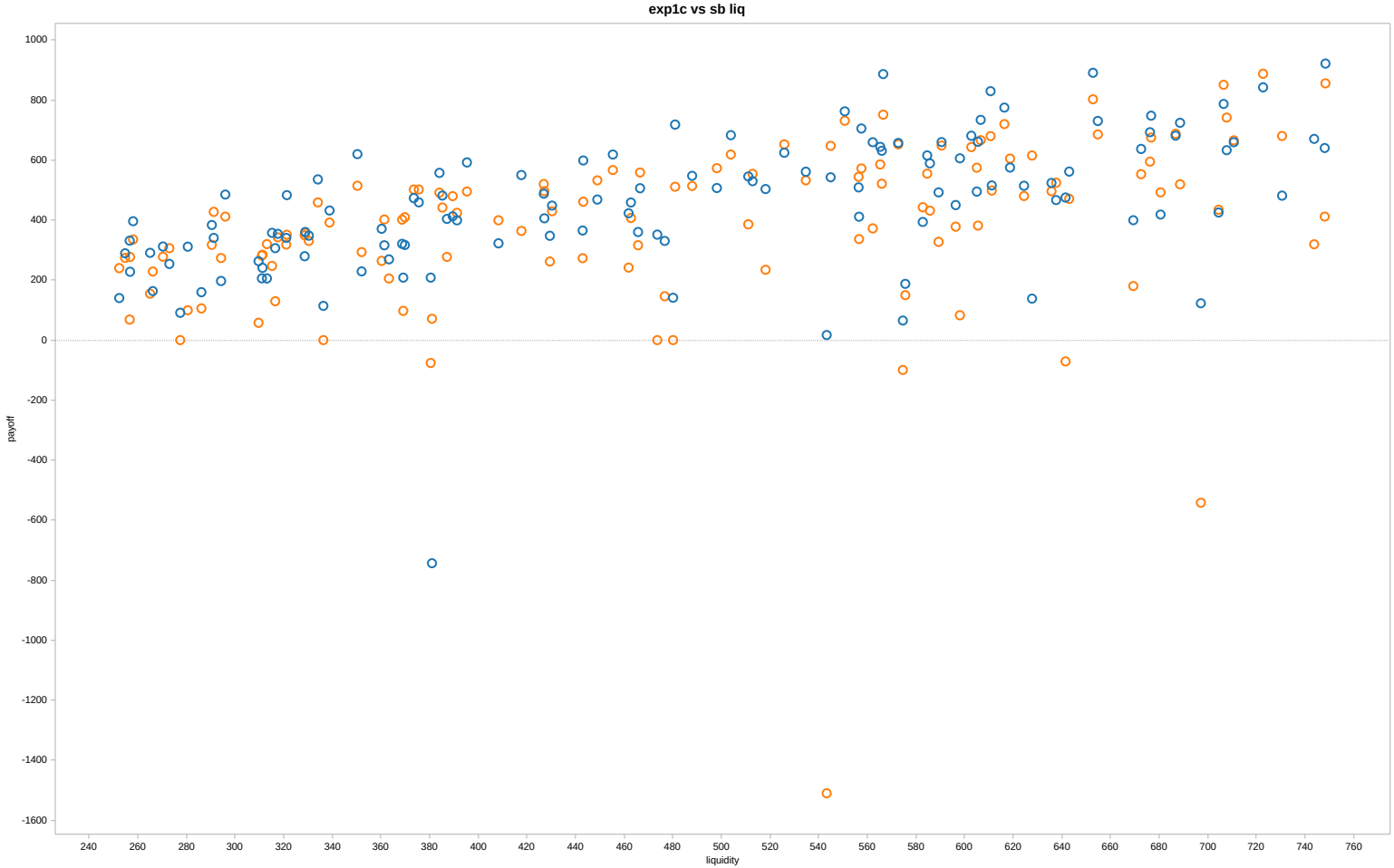


Liquidity vs. payoff. Color shows details about Clock. Shape shows details about Clock. The data is filtered on Day, which ranges from 1 to 4.

Clock

- clock
- sbid

Figure A6.20. Payoff as a function of liquidity



Liquidity vs. payoff. Color shows details about Clock. The data is filtered on Day, which has multiple members selected.

Clock

- clock
- sbid

Figure A6.21. Learning in experiment 3.1

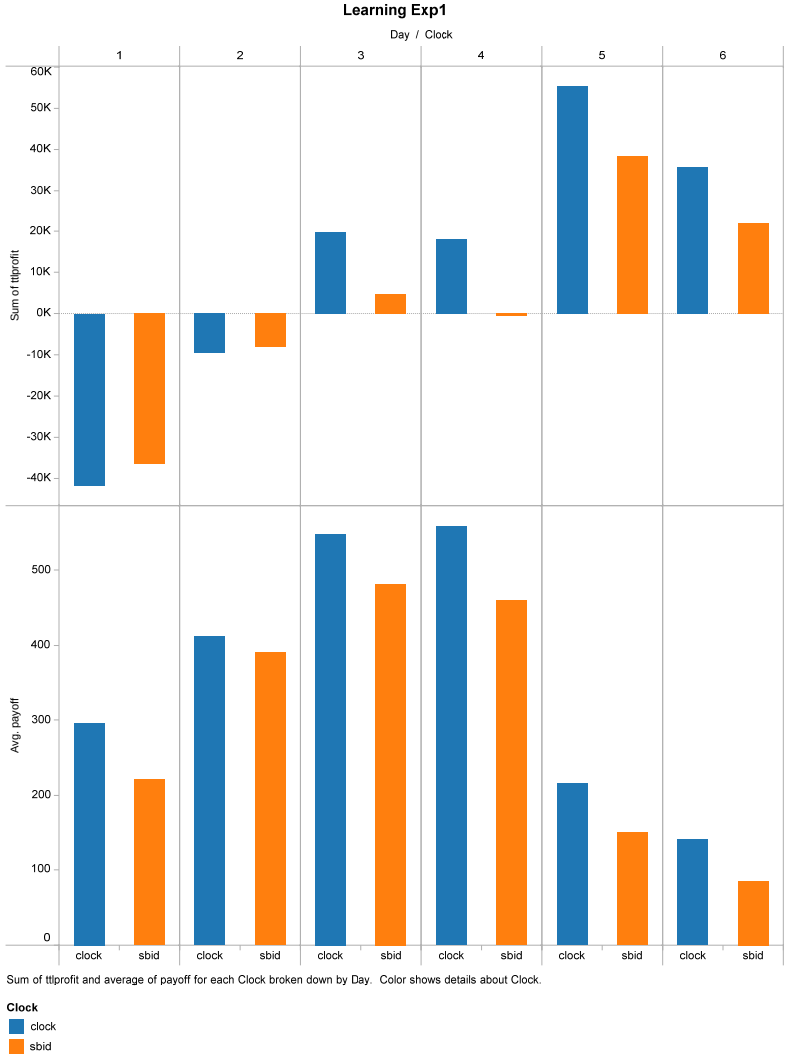
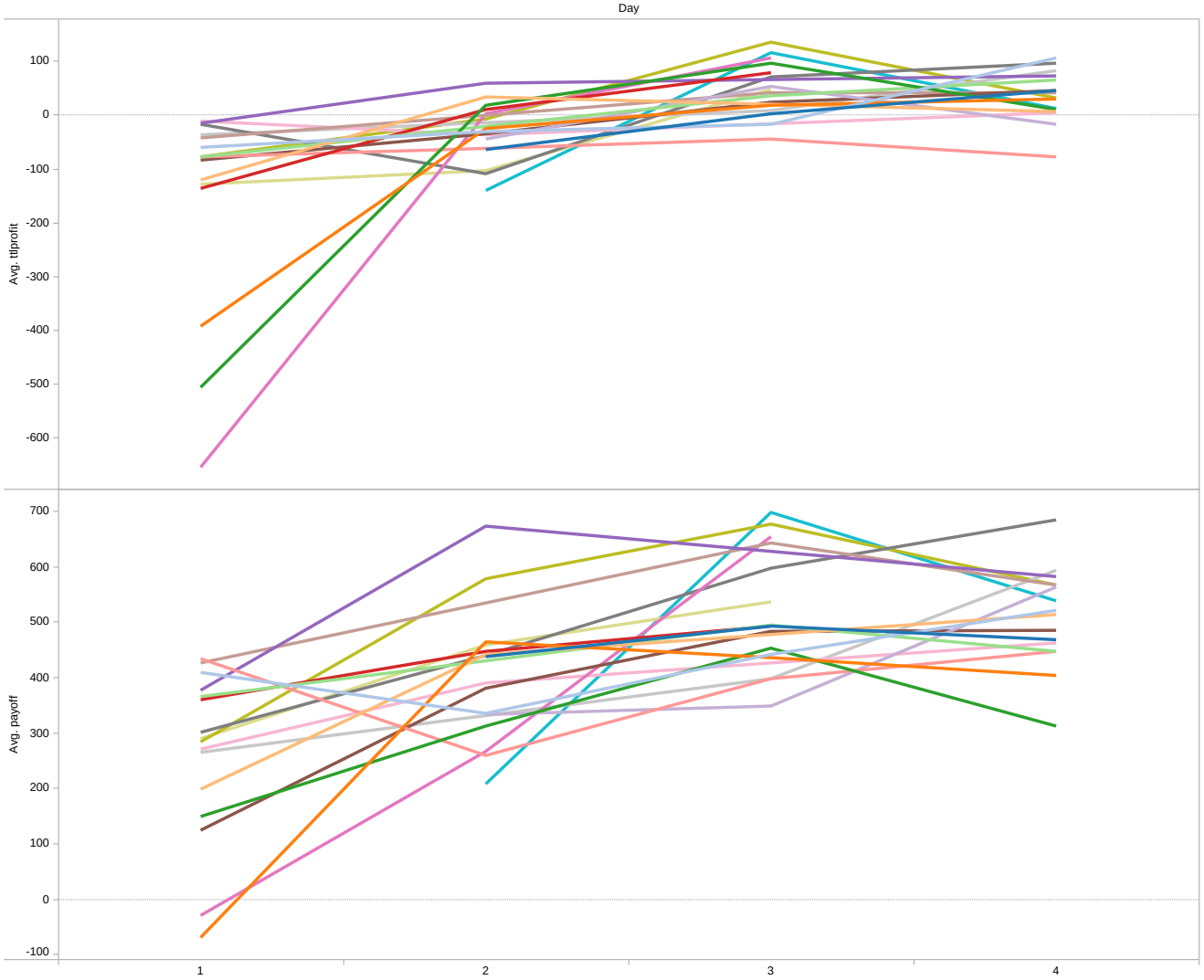


Figure A6.22. Learning in experiment 3.1

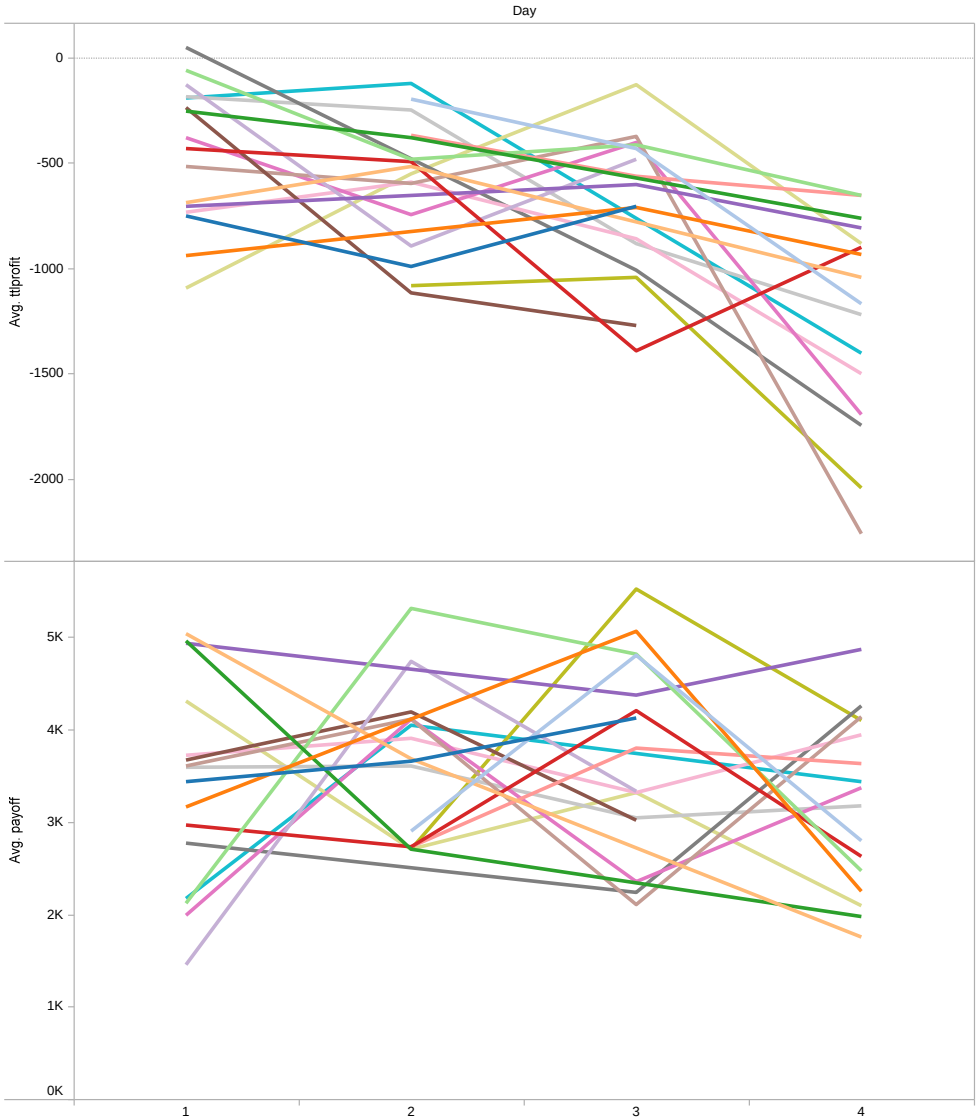
Exp1 Learning2



Comparing the trends of average of ttlprofit and average of payoff with Day. Color shows details about subject. The view is filtered on Day, which has multiple members selected.

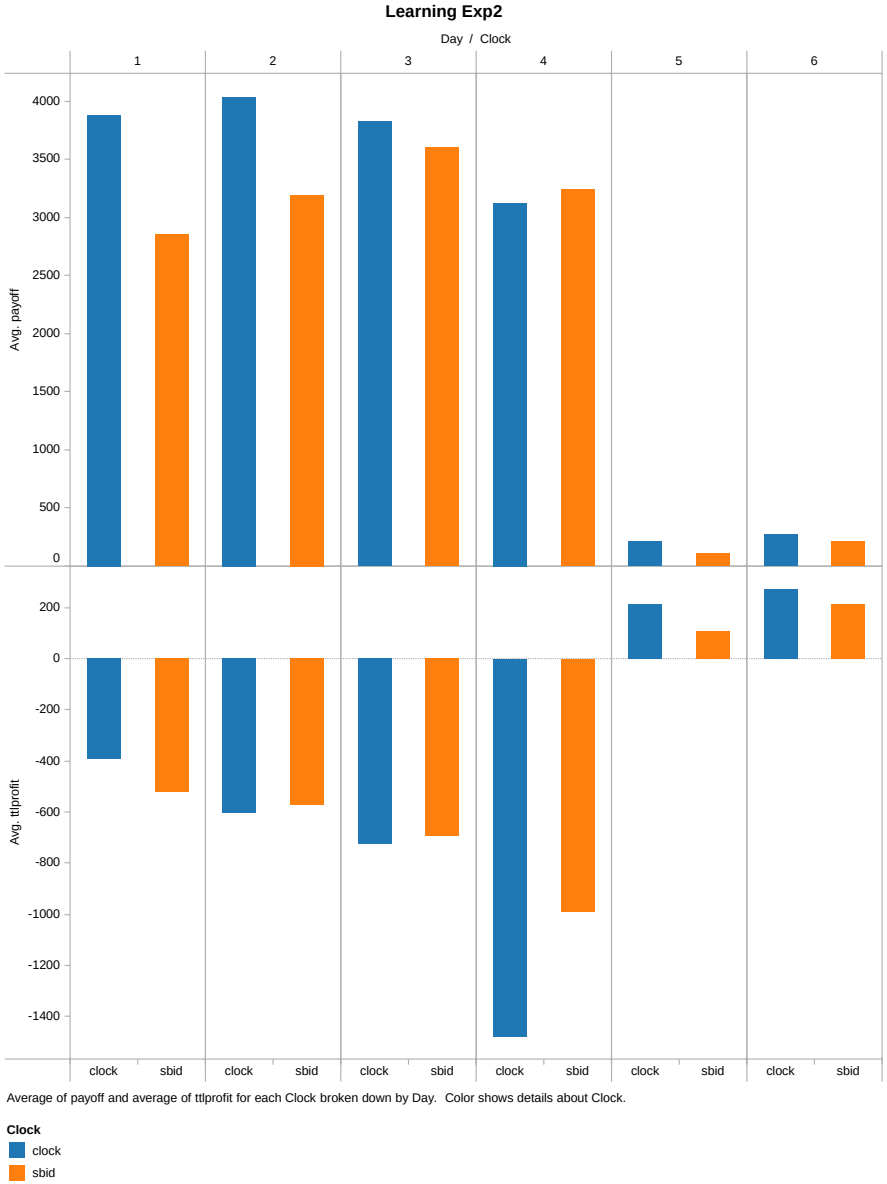
Figure A6.23. Learning in experiment 3.2

Exp2 Learning2



Comparing the trends of average of ttlprofit and average of payoff with Day. Color shows details about Subject. The view is filtered on Day, which has multiple members selected.

Figure A6.24. Learning in experiment 3.2



Average of payoff and average of ttlprofit for each Clock broken down by Day. Color shows details about Clock.

Clock

clock

sbid

Appendix 7

Figures from Experiment 3.2: A Reference Price Auction without Liquidity Needs

Figure A7.1. Supply and demand by pool (day 1, auction a)

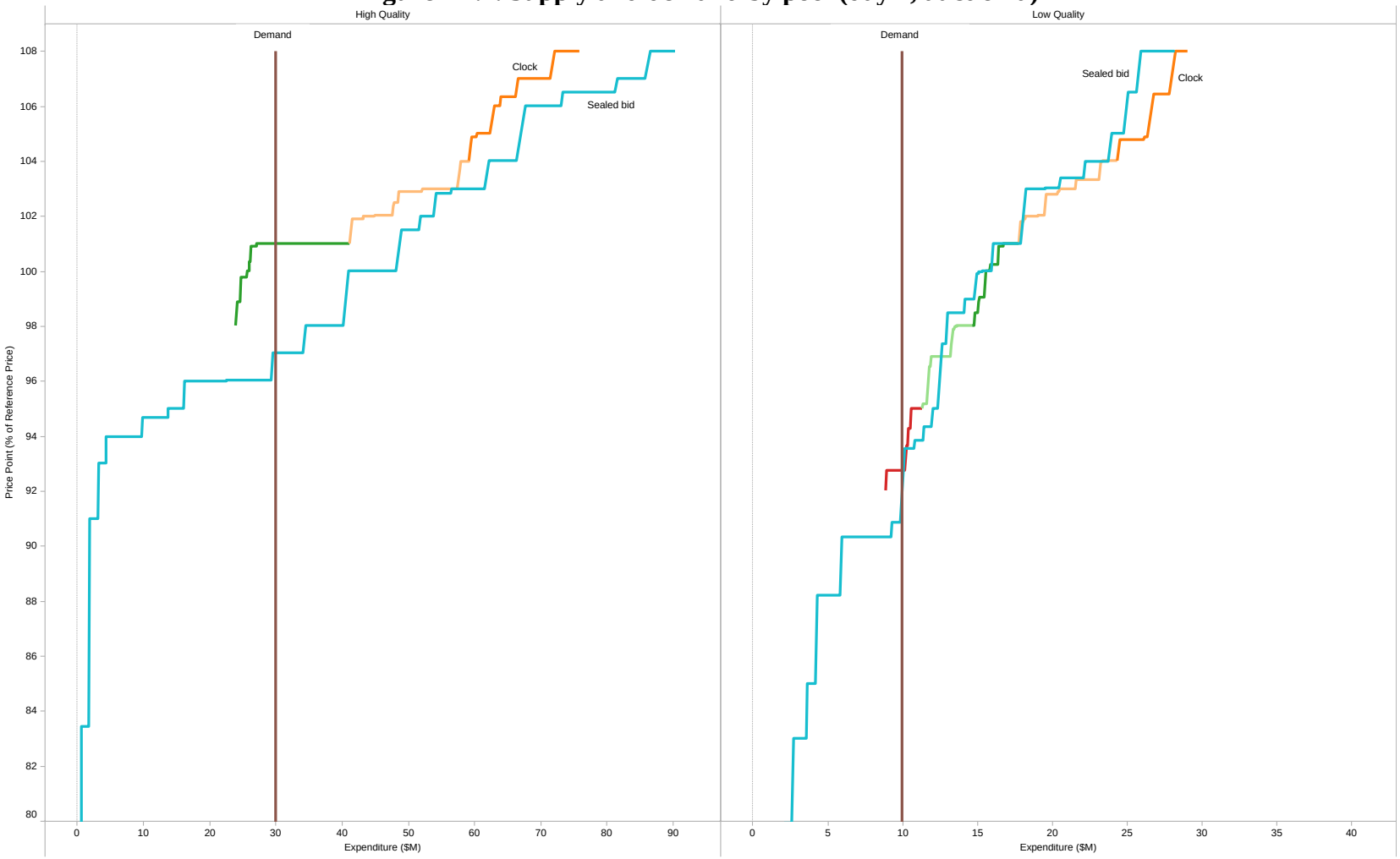


Figure A7.2. Supply and demand by pool (day 1, auction b)

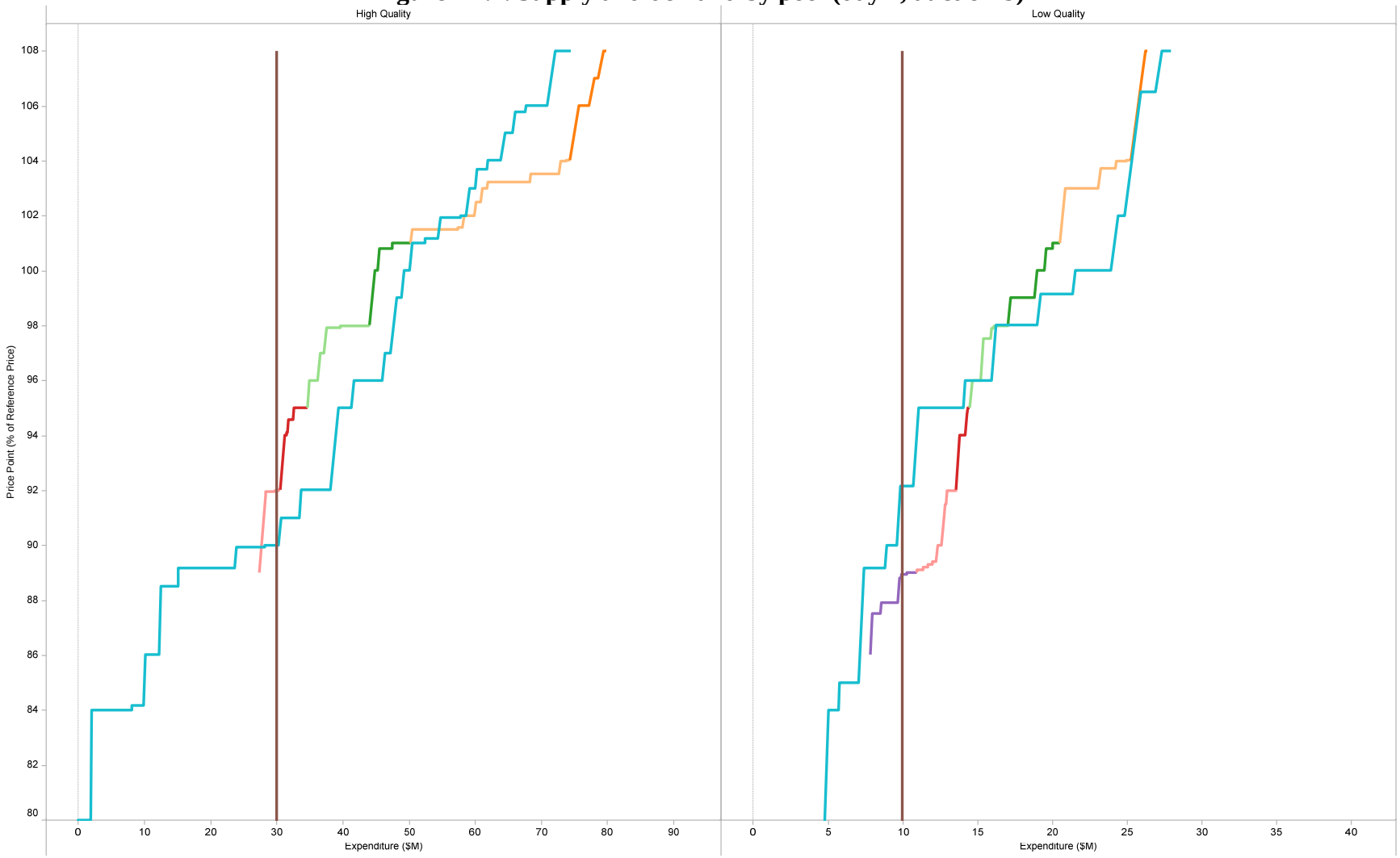


Figure A7.3. Supply and demand by pool (day 2, auction a)

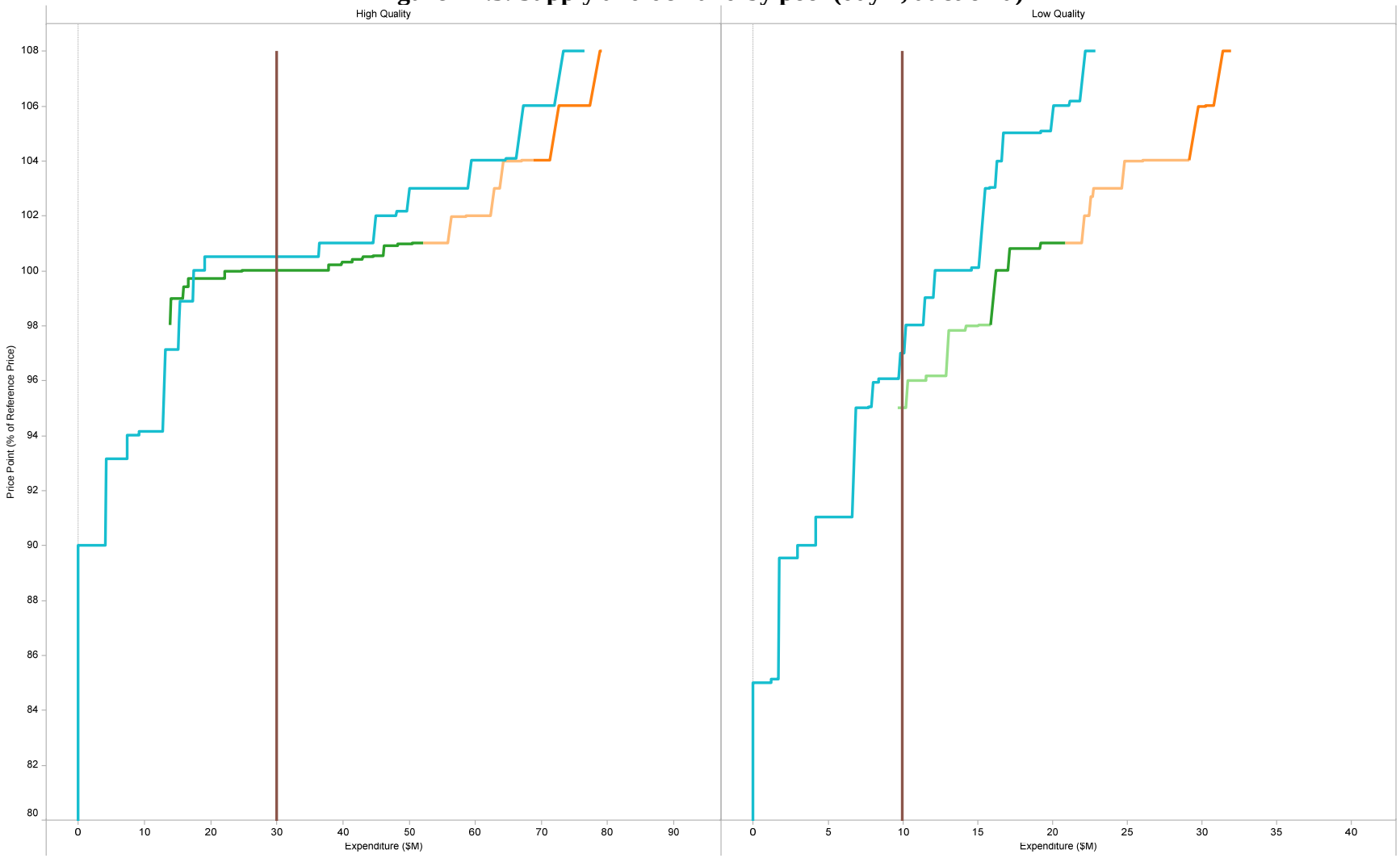


Figure A7.4. Supply and demand by pool (day 2, auction b)

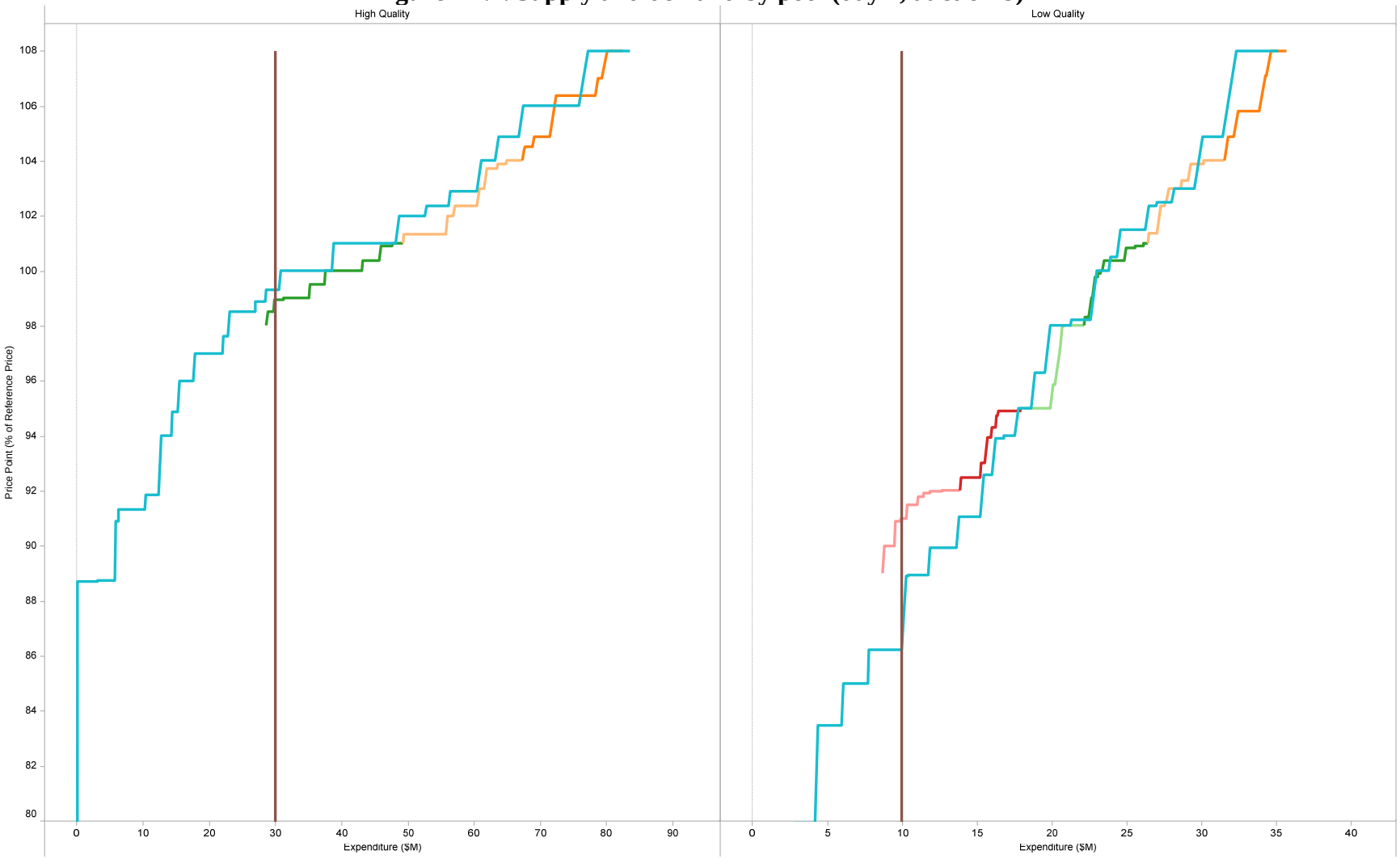


Figure A7.5. Supply and demand by pool (day 3, auction a)

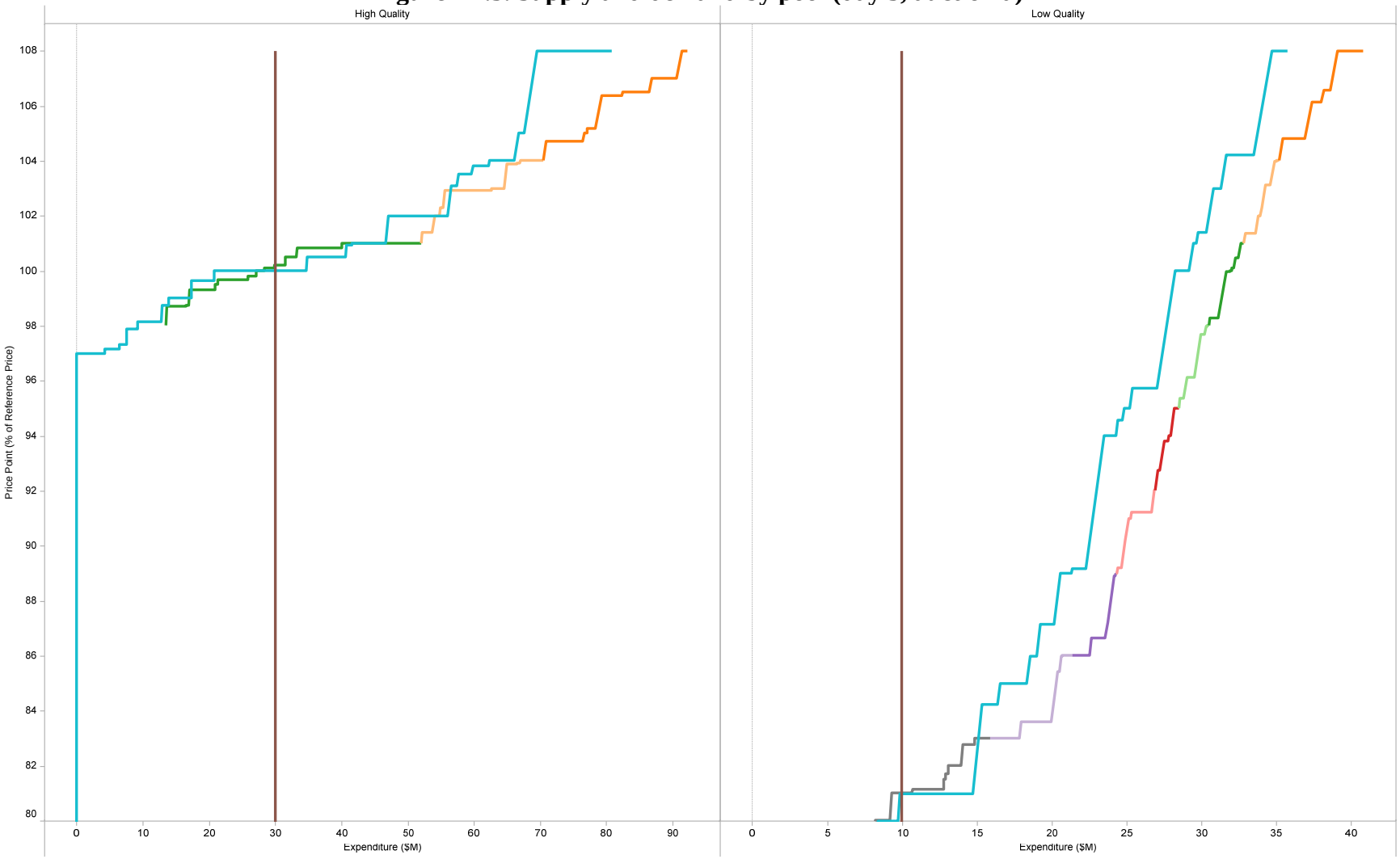


Figure A7.6. Supply and demand by pool (day 3, auction b)

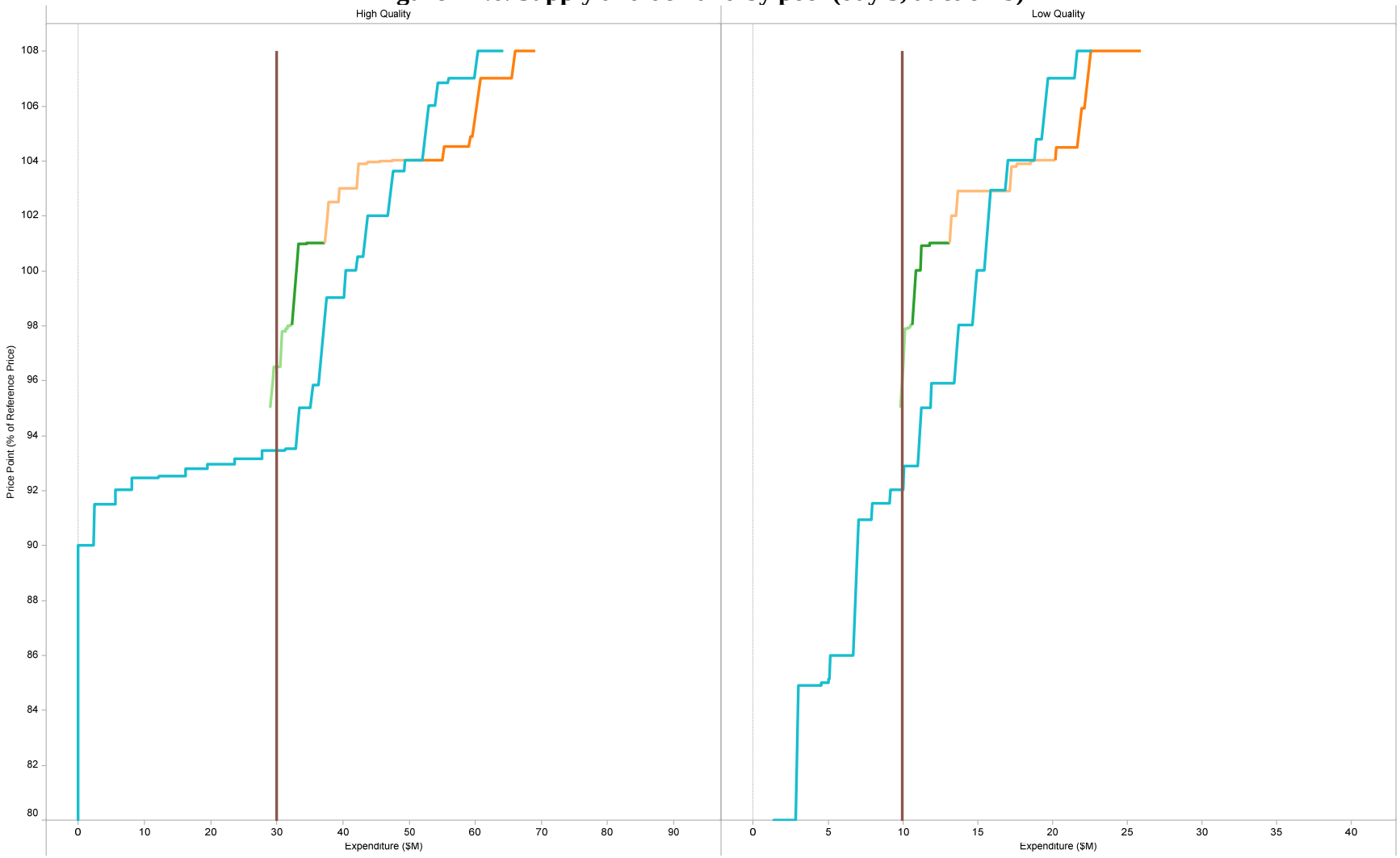


Figure A7.7. Supply and demand by pool (day 4, auction a)

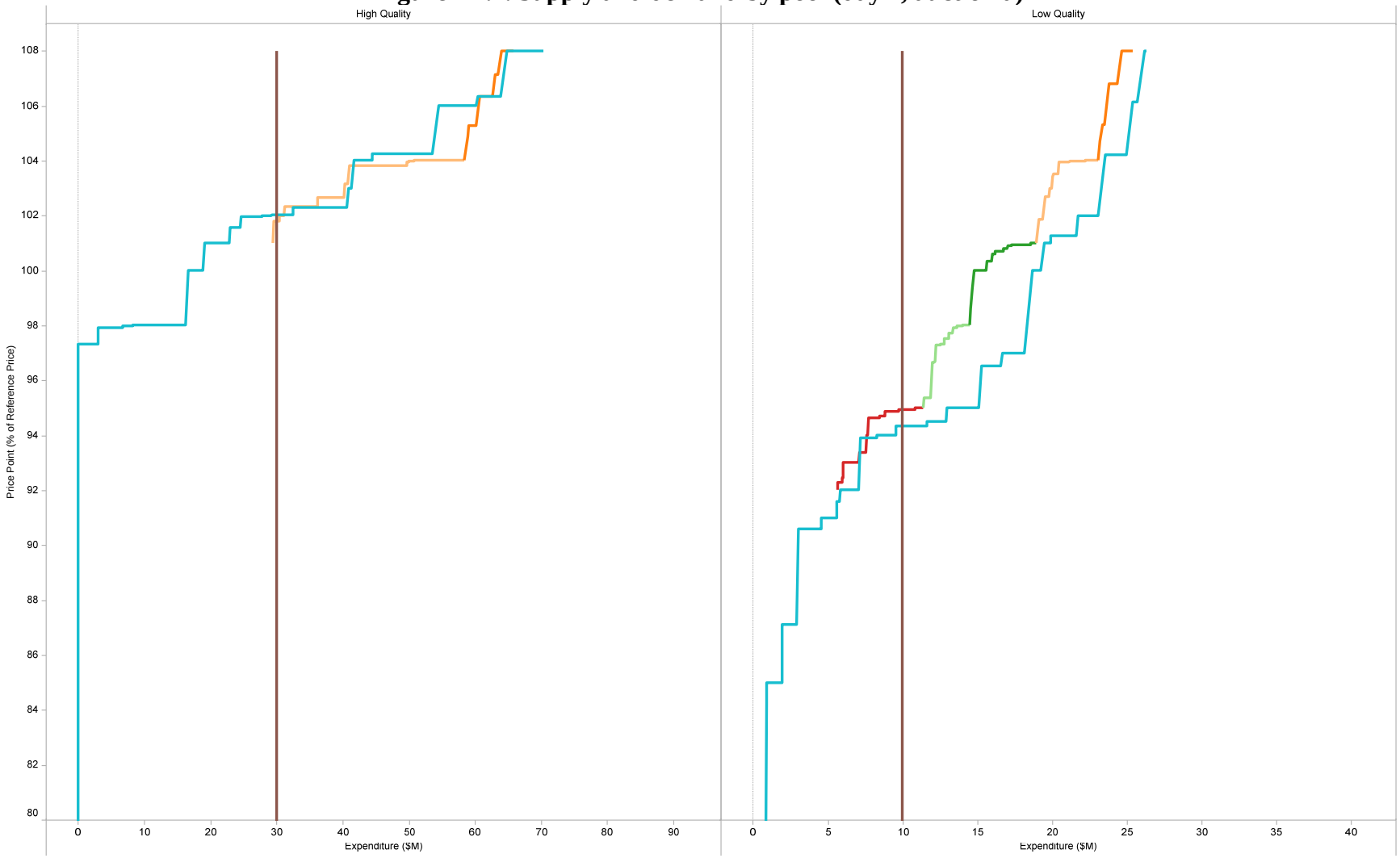


Figure A7.8. Supply and demand by pool (day 4, auction b)