Experimental Testing of Possible Designs for the Australian Carbon Pollution Permit Allocation Auction

Prepared for: Department of Climate Change & Energy Efficiency

May 2010

transport infrastructure | community infrastructure | industrial infrastructure | climate change



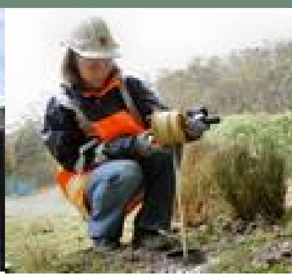


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Table of Contents

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Date: 24 May 2010

Executive Summary

This study experimentally tests different design features of primary auctions to allocate Australian Emissions Units (AEU) to the entities covered by the proposed emissions trading scheme. On the basis of our experimental results and the theoretical and empirical academic literature on permit auction design, we recommend an appropriate auction format.

The key objectives of the Government in relation to the permit allocation auctions are to promote allocative efficiency and efficient price discovery, as well as to raise auction revenue, with the former objectives given priority over the latter. In the proposed Australian scheme – called Carbon Pollution Reduction Scheme (CPRS) – each permit will have a date stamp (vintage), indicating the year in which it becomes applicable. Those permits can be banked (used later than date stamp) and to a limited extent also borrowed (used earlier than date stamp). It is planned to auction both current and future vintages.

Using experimental methods, this study addresses the following main questions:

1. Should the auction follow a sealed-bid approach or should it be implemented as an ascending clock auction with proxy-bidding?
2. If a clock auction is used, should the aggregate demand be revealed during the auction?
3. Should multiple vintages be auctioned off simultaneously or sequentially?

To answer these questions, we developed an experimental design consisting of two dimensions: *auction format* (sealed bid, clock auction without revelation of aggregate demand, clock auction with revelation of aggregate demand) and *market environment* (1 vintage, 2 vintages auctioned sequentially, 2 vintages auctioned simultaneously, 2 vintages auctioned simultaneously with subsequent secondary market). In a 3x4 factorial design we tested all cells in those two dimensions, resulting in a total of 12 experimental treatments. An additional treatment tested the robustness of the eventually recommended design (see below) with a larger number of traders.

From January to March 2010 we conducted experiments at the University of New South Wales (UNSW) and at Karlsruhe University (KU). Our analysis relies on 1,120 participants in 75 experiment sessions, participating in a total of 447 auctions.

With respect to Questions 1 and 2, all three *auction formats* perform rather similarly in our experiments with respect to efficiency, auction revenues, and bidder profits. This is true in all single-vintage and two-vintage market environments tested, and it is consistent with the existing experimental literature. However, there is some indication that an open clock format yields a lower volatility of final auction prices than a closed clock or a sealed bid format.

With respect to Question 3, we find no support for the conjecture that a simultaneous auction of two vintages yields higher efficiency than auctioning them off sequentially. To the contrary, we obtain evidence that a sequential auction yields more efficient allocations, higher auction revenues, and better price signals.

Given the lack of evidence of superiority of one of the auction formats with respect to efficiency, other characteristics of an auction such as price volatility or simplicity take a more prominent role in applied auction design. Based on a prudential weighing of theoretical considerations, empirical evidence on previous permit auctions and our experimental findings we make the following recommendations for the CPRS auction design:

The CPRS auctions should:

1. Apply the format of a clock auction with proxy-bidding, and
2. Reveal aggregate demand after each round, and
3. Be conducted sequentially if more than one vintage is auctioned at an auction event, with the earliest vintage auctioned first.

In the longer term, once liquid secondary markets have evolved, we recommend that switching to a sealed bid format be considered. We also recommend reviewing the performance of sequential auctioning of multiple vintages and considering a change to a simultaneous auction if necessary. We suggest that an appropriate time for such a review may be after the end of the year of the first vintage covered by the CPRS.

1. Introduction

1.1 Objective

The objective of this study is to test experimentally competing designs for the auction of Australian Emissions Units (AEU) and, based on the experimental results, to advise the Government on an appropriate auction design.

The review of the related literature in Chapter 2 identifies auction design issues that warrant experimental testing. Chapter 3 summarizes discussions at the project initiation workshop (held in Canberra on 29 October 2009), lays out the eventual experimental design, and describes the specifics of the experimental implementation. Chapter 4 presents the results of the experiments. Chapter 5 discusses those results with respect to different auction design options, by contrasting them with the results from the literature review and other considerations. Finally, Chapter 6 presents our recommendations, including a detailed description of the auction design and its micro rules. Appendices comprise additional micro rules and an electronic collection of experiment material, including instructions, software code, and data.

1.2 Relevant Features of the Carbon Pollution Reduction Scheme

In April 2010 the Prime Minister announced Australia would not introduce the Carbon Pollution Reduction Scheme (CPRS) until after the end of the current commitment period of the Kyoto Protocol and only when there is greater clarity on the actions of other major economies including the US, China and India. As at the time of writing of the report, no decision had been taken on a new start date for the CPRS.

The policy positions outlined in this report are based on the Government's CPRS legislation and policy pronouncements as in force at the time of the Prime Minister's announcement.

The proposed Australian scheme – called Carbon Pollution Reduction Scheme (hereafter CPRS) - will cover about 75% of all greenhouse gases (GHG) emitted in Australia. The total amount of permits the Government plans to issue (the scheme's cap) is yet to be decided. It will take into account, among other factors, Australia's international commitments.[1]

Scheme compliance years are aligned with the Australian financial year, running from 1st of July to 30th of June. The scheme will start with a fixed permit price in the first year with an unlimited quantity of permits. The cap-and-trade scheme (full trading) is planned to start in the subsequent year. Each permit will have a date stamp (vintage), indicating the year in which it becomes applicable. Permits can be banked without restrictions and a small share of borrowing (5%) will be allowed.[2]

The first auction of future permits is intended to take place during the first year of the scheme, as is the allocation of free permits for the first year of full trading. According to DCCEE estimates at time of writing, around 63.5% of the permits would be offered in the auction; around 28% would be allocated free to energy-intensive trade-exposed industries (hereafter EITE industries); 6 % to specified emissions intensive activities

[1] Australia's international target is a reduction between 5% and 15% below 2000 levels by 2020. In the event that an ambitious global goal were to be reached and additional conditions met (e.g. stabilisation of atmospheric CO2-e at 450ppm, advanced economy reduction targets, in aggregate, of at least 25% below 1990 levels by 2020), this target rises to 25%. Australia submitted this whole target range to the UN in January 2010.

[2] *Banking* means that permits which have not been used for compliance in one year can be saved for use in future years, e.g. vintage of 2012-13 can be used for compliance in 2014-15. Permits thus do not have an expiry date. *Borrowing* means that liable companies will be allowed to discharge up to 5% of their obligation by surrendering Australian Emissions Units for the following year.

undertaken by coal fired electricity generators and 2.5% to emissions intensive underground coal mines under the coal sector adjustment scheme (CSAS)."

Based on the allocation rules and the structure of Australian industry, it is expected that very few businesses will have a surplus of permits for sale. Even though emissions-intensive, trade-exposed (EITE) industries will receive permits for indirect emissions (electricity consumed), and thus will have more permits than needed to meet their obligations arising from the activities for which the free permits are provided, most of these companies will use the freely allocated permits to cover direct emissions from other activities for which they are responsible and do not receive free permits. Thus, most recipients of free permits will not be net sellers.

A transitional price cap will apply for the first three years of the scheme, starting at around $40 per tonne in 2010/11 terms and rising at 5 per cent in real terms per annum. Operation of the scheme will be reviewed at an early stage to determine whether the permit price cap should be maintained for more than four years.

According to the *White Paper* it is expected that around 1,000 companies will be covered by the emissions trading scheme. These companies are asymmetric in size. Public data from the first year of the Australian National Greenhouse and Energy Reporting System (NGERS), released on 26 February 2010, suggest that liability may be highly concentrated. We note that emissions coverage of NGERS is somewhat narrower than that proposed for the Carbon Pollution Reduction Scheme (hereafter CPRS), the liability threshold for the first year is higher, and the definition of corporate liability is different. Acknowledging these differences, the data are nevertheless illuminating: of the 335 Mt of direct emissions reported, 80% was accounted for by approximately 35 businesses (calculated from Department of Climate Change, 2010). Financial institutions and professional dealers will not be excluded from participating in the auction and the secondary permit markets. Therefore financial institutions and professional dealers might play a significant role (e.g. purchase permits for smaller emitters).

In order to further explore the issue of permit demand by Australian companies, we have made adjustments to convert the emissions reported under NGERs into permit purchase requirements. In doing so, we drew extensively on information provided by individual companies in their environmental and sustainability reporting. Nevertheless, we stress that these estimates are indicative only, because of the many uncertainties involved. These adjustments include:

- Emissions attributable to combustion of petrol, diesel and other petroleum products by small users are allocated "upstream" to the petroleum refining and marketing companies. Note that this is a "guesstimate" since many business users of petroleum products will have the option of either "upstreaming" their obligations or taking on the liability themselves and the outcome cannot be known until the CPRS starts.
- Similarly, estimated emissions attributable to combustion of natural gas by small users are allocated "upstream" to gas retailers.
- Estimates have been made of the free permits which may be made available to individual electricity generation businesses under the Electricity Sector Adjustment Scheme. The estimates are based on total electricity sent out in 2008-09, as reported by the Australian Energy Market Operator (AEMO), together with AEMO data on the emissions intensity of individual power stations. The calculations suggest that about 75% of the free permits will go to the Victorian brown coal generators, 12% to NSW generators, 6% to Queensland, 4% to WA and 3% to SA.
- Similarly, estimates have been made of the free permits which may be made available to businesses involved in EITE activities. These estimates made use of formal assessments of eligible activities for which approval has so far been published, and indicative data provided in the *White Paper* and the list of activity

definitions for other activities (Department of Climate Change, 2009a, 2009b). The estimates suggest that the largest shares of free permits will go to the aluminium, steel and cements industries, in that order, and that together they may receive up to 40% or even more of the total. It is difficult to be more precise because some of the intensity baselines have not yet been published.

- No adjustment has been made to emissions of coal mining companies, because it has not yet been determined what form the assistance to coal mining will take.

Table 1.1: Indicative Emissions and liability shares for entities with the thirty largest liabilities

Company	"Upstreamed" liabilities?	Share of 2007-08 emissions for CPRS covered sectors		Cumulative share of NGERS reporting entities
		Individual	Cumulative	
1		5.2%	5.2%	0.4%
2	Yes	5.0%	10.2%	0.9%
3		4.7%	14.9%	1.3%
4		3.5%	18.4%	1.7%
5	Yes	3.4%	21.8%	2.1%
6		3.0%	24.9%	2.6%
7		2.8%	27.7%	3.0%
8	Yes	2.7%	30.3%	3.4%
9	Yes	2.5%	32.9%	3.8%
10		2.5%	35.4%	4.3%
11		2.2%	37.6%	4.7%
12	Yes	2.0%	39.6%	5.1%
13		1.7%	41.3%	5.6%
14		1.6%	42.9%	6.0%
15		1.6%	44.5%	6.4%
16		1.6%	46.1%	6.8%
17		1.4%	47.5%	7.3%
18		1.4%	48.9%	7.7%
19		1.1%	50.0%	8.1%
20		0.9%	50.9%	8.5%
21	Yes	0.9%	51.8%	9.0%
22		0.9%	52.7%	9.4%
23		0.8%	53.5%	9.8%
24	Yes	0.8%	54.4%	10.3%
25		0.8%	55.2%	10.7%
26		0.7%	56.0%	11.1%
27i		0.6%	56.5%	11.5%
28		0.6%	57.1%	12.0%
29		0.5%	57.7%	12.4%
30		0.5%	58.2%	12.8%

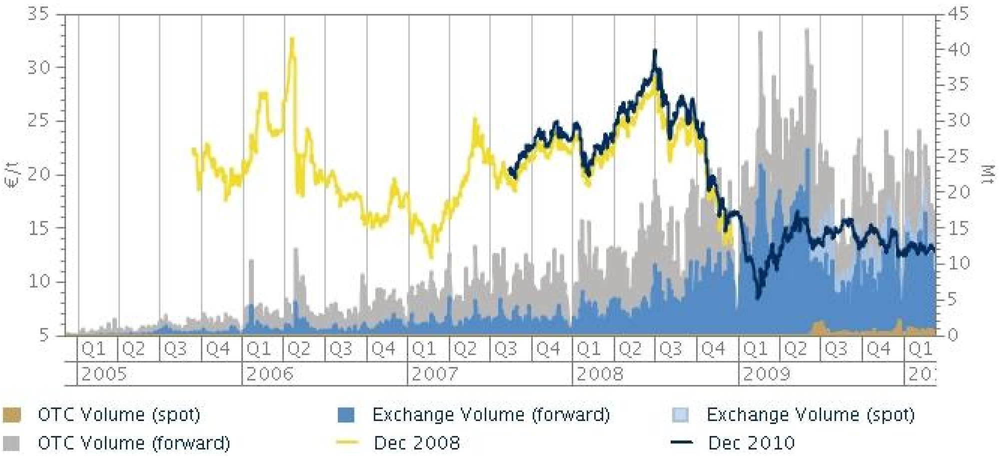
Table 1.1 shows our estimates of the net permit requirements of the companies with the 30 largest net requirements, placed in descending order of permit purchase requirement. As previously noted, these figures should be treated as indicative only, because of the many uncertainties and assumptions which had to be made in working from data that is in the public domain.

The largest 16 companies comprise the four major oil refining and marketing companies, for which "upstreamed" liabilities from customers account for the great bulk of liabilities, and twelve coal fired electricity generation businesses. The remaining 14 businesses in the list consist mainly of the two major electricity and gas retailers (with "upstreamed" gas emission liabilities), coal mining companies, oil, gas and LNG producing companies, and some additional electricity generation companies.

It can be seen that the companies with the 16 largest permit purchase obligations account in total for nearly half of the total emissions from covered emission sectors in 2007-08, but only 7% of current NGERS reporting entities (and by implication, given the relative scope of liability definitions, a much smaller proportion of entities with direct CPRS liabilities). With the permits being offered at auction accounting for around 63.5% of total permits, as noted above, the proportion of auction demand arising from the companies with the largest 16 obligations is nearly 75%, and the 30 businesses shown in Table 1.1 will require over 90% of all permits to be auctioned.

It is quite possible that the secondary market will not be strongly liquid, especially in the first years. Low liquidity in the initial phase of an emissions trading scheme seems common. For example, as Figure 1.1 shows, the EU Emission Trading Scheme (EU ETS) volume of EU Allowances (EUAs) trading "increased four- to fivefold from the first to the last quarter of 2005, more than tripled between 2005 and 2006, increased another 75 per cent from 2006 to 2007 and rose by a further 84 per cent from 2007 to the end of 2008" (Ellerman et al 2010). Similar developments have been observed in the Regional Greenhouse Gas Initiative (RGGI) which had the first auction in September 2008 and the compliance period started in January 2009. In the RGGI 218,000 allowances were traded on average per day in September 2008 (annual allocation is roughly 180 million allowances), and 6,181,000 per day in June 2009, increasing by a factor of 30 in just 9 months (Potomac Economics 2009).

Figure 1.1: Volume of secondary market activity in the EU ETS



Notes: Figure 1.1 shows daily volumes including all traded products and contracts. The volume is aggregated and not broken down to vintages or different products.
Source: Point Carbon 2010

1.3 Auction Design

In its 2008 *White Paper* (Commonwealth of Australia 2008), the Government formulated its key objectives for the permits auction system:

- "Promote allocative efficiency (…) with a minimum of risk and transaction costs.
- Promote efficient price discovery. (…)
- Raise auction revenue (consistent with other objectives). (…)"

Should the last objective of revenue raising conflict with allocative efficiency and effective price discovery, the *White Paper* stipulates that the first two objectives should be given priority over revenues.

Apart from the auction objectives, the *White Paper* states that the preferred auction type for multiple vintages is a simultaneous ascending clock auction with proxy bidding (see Policy positions 9.11-9.13). In the first two years net suppliers would be allowed to contribute their quantities to the supply.

The first auction will take place as early as feasible, before the start of the Scheme. Permits will be auctioned in advance, and there will also be a “wrap-up” auction after the end of a financial year, one month prior to the final surrender date. Once the scheme is running fully, for each vintage there will be an auction in each of the three years preceding the respective vintage. During the year of the vintage, monthly auctions are envisaged. Thus, the total supply will be spread out over 16 auctions including the wrap-up auction. Depending on the choice of the auction dates, there could be up to five vintages auctioned off simultaneously (one of the previous year, one for the current vintage, and three for future vintages). The 2010 version of the Bill (Commonwealth of Australia 2010) included deferred payment arrangements for auctions of future vintage permits before the end of 2013.[3]

The details of the auction design will be set out in a Ministerial determination under section 103 of the CPRS Act. It gives the power to the Minister to determine the policies, procedures and rules applicable to the auction, including issues such as auction type, participants, timing, deposits, and the like. The draft determination will be consulted on prior to its being made. The determination must be made after passage of the CPRS legislation and prior to the first auction.

Consistent with the Ministerial determination, micro-design features, including elements of the micro-rules, are likely to be published by the Australian Climate Change Regulatory Authority (ACCRA) on its website and/or embodied in auction guidance manuals. Such elements may not necessarily be included in detail in the determination.

[3] For the latest version of the Carbon Pollution Reduction Scheme Bill 2010 see http://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22legislation%2Fbillhome%2Fr4281%22

2. Literature Review

The literature review identifies relevant auction design features to be tested experimentally. The basis for this review is the *White Paper* and earlier reports as well as the recent academic literature. Guiding questions are:

Has the proposed auction design been used in similar circumstances and, if yes, how did it perform?

Has the proposed auction design been experimentally tested and, if yes, what do we learn from these experiments?

An earlier draft of the literature review served as a basis for the workshop held at the Department of Climate Change on 29 October 2009. At that workshop the proposed experimental treatments were discussed and further refined, resulting in the experimental design presented in Chapter 3.

2.1 Overview of Relevant Literature and Auction Experience

The *White Paper* drew on a number of papers enumerated in the attached literature review list, most prominently (see *White Paper* p. 9-7) the Evans & Peck (July 2007) report on auction design which was commissioned by the National Emissions Trading Taskforce and to which two of the present authors (Betz and Seifert) were key contributors.

Subsequently, and apparently during the *White Paper* drafting stage, the DCC commissioned Tradeslot Pty Ltd ("Tradeslot") to provide an additional report on the key design elements of auctions (auction type, advance auctioning of future vintages, auction timing and frequency, and timing of payments for permits) under Australia's CPRS (Tradeslot 2008). This study was finalized in October 2008. The focus of that study was on implementation risks (price, demand, credit, systems) which were identified as primary concerns by the Department of Climate Change (hereafter DCC) (Tradeslot 2008, p. 3).[4]

The *White Paper* carefully integrates the studies by Evans & Peck and Tradeslot as well as numerous comments and other reports on related auctions emerging before its appearance (including the RGGI report of October 2007 but apparently not the April 2008 follow-up study; see Holt et al. 2007, 2008), and formulates a series of thirteen "policy positions" and statements on "operational features of the auction" (see pp. 9-28 – 9-29).

Since the *White Paper* was published, auctions have taken place in some EU countries, namely Austria, the UK and Germany, in Phase 2 of the EU ETS[5], as well as in the Northeast of the United States (the RGGI initiative for which Holt et al. 2007, 2008 helped to lay the foundation). The available information on those auctions is also included below.

The experiences with auctions in the EU ETS context have been summarized in several reports of which we believe Ockenfels (2009, currently only available in German), who advised the European Energy Exchange on the design of Germany's permit auction market, to be the most careful and perceptive one. However, the relevance of the

[4] "*Price risk*: the risk that prices will diverge from market fundamentals due to auction design choices and policy decisions; *Demand risk*: the risk that demand will be artificially lowered during the auction design choices and policy decisions; *Credit risk*: the risk that successful bidders at the auction will not follow through with payment; *Systems* risk: the risk that auction participation is artificially reduced due to bidders having troubles using or accessing the system." (Tradeslot 2008, p. 3)

[5] Total amount to be sold or auctioned is around 3% of EU-budget 2008-2012. The following countries are auctioning or selling allowances (based on National Allocation Plan data): Germany (9% or 40.0 Mio. EUA/a around 60% of total auctioning amount of EU), UK (7% or 17.2 Mio. EUA/a), Netherlands (3.7% or 3.2 Mio. EUA/a), Lithuania (2.8% or 0.5 Mio. EUA/a), Hungary (2.7% or 0.5 Mio. EUA/a), Austria (1.3% or 0.4 Mio. EUA/a), Ireland (0.5% or 0.1 Mio. EUA/a), Denmark (0.3% or 0.1 Mio. EUA/a).

report is reduced by the assumption that secondary markets exist at the time of inauguration of the primary permit market, a condition which is questionable in the current context. Ockenfels (2009) furthermore focuses on sealed-bid auctions.

In addition, a couple of experimental studies have appeared complementing the RGGI experimental report.[6] These studies do not directly apply to the Australian context (e.g. number of participants; see below) but they point out a potential weakness, namely, the potential for collusion, of the proposed multi-unit ascending clock auction format. They also suggest ways to address these problems (e.g. ensuring a high number of participants). The only experimental study so far that speaks to the current policy position of a simultaneous clock auction is Porter et al. (2009) but it deals with the Virginia NOx auctions. Importantly, the auction format implemented in Virginia was a sequential clock auction, and not the recommended simultaneous clock auction format.

We finally note that the Government's decisions in 2009 to postpone the schedule laid out in the *White Paper* and to set a fixed price for the first year of the scheme, as well as the increased political uncertainty of the legislation being passed after the CPRS Bill was defeated twice in the Senate, were found to have led to a drying up of activity on already existing secondary markets (Macquarie Economics Research 2009).

2.2 Auction Type and Design Features

2.2.1 Auction Type

In this section we discuss uniform pricing which can be implemented in both sealed bid and clock auctions, and pay as bid (discriminatory) pricing which can be implemented, for example, in sealed bid discriminatory auctions, but not in clock auctions

The issue of an appropriate auction type is prominently addressed in Holt et al. (November 2007, there in particular pp. 16 - 21) and their April 2008 addendum. They tested several different auction types experimentally (see more details below). Ockenfels (2009) sees the major advantage of clock auctions to be their ability to discover prices, which, he argues, is of little importance in permit auctions if secondary markets exist. The additional advantage of clock auctions, the possibility to auction spot and future vintages simultaneously, is a minor issue in emissions trading schemes such as the EU ETS, which has compliance periods of five (Phase 2) and eight years (Phase 3), respectively, with fully fungible permits within these periods. Mandell (2005) points out that ascending clock auctions provide more information, which is important in the beginning of trading schemes when secondary markets are not efficiently operating.

In their Final Report on the auction design for selling CO_2 emission allowances under the RGGI, and their April 8, 2008 addendum, Holt et al. (2007) propose a sealed-bid auction (with a uniform pricing rule) which is in line with practices elsewhere. However, it stands in contrast to the *White Paper's* key policy positions of a simultaneous clock auction. The only experimental study which is roughly in line with the proposed Australian auction design is Porter et al. (2009), investigating the Virginia NOx auctions. They find clock auctions superior in terms of revenue (not different in their efficiency properties) to sealed-bid auctions when demand is relatively elastic. Given the unlimited supply of permits at a fixed price (price cap) in the early years, and the unlimited use of international credits, it seems likely that the demand curve for permits in Australia will be rather elastic.

[6] We refer here to the April 2008 follow-up study to the RGGI report of October 2007 (cited as Holt et al. 2008) and the related papers by Burtraw et al 2010, Shobe et al 2010, Goeree et al 2010.

A major argument against clock auctions by Holt et al. (2007) is the potential for collusion that clock auctions allegedly bring about. In Holt et al. (2008) this objection was subject to experimental testing by additional sessions with clock auctions in which participants could discuss any aspect of the auction in a chat room that was open prior to each round of bidding: "The results provide strong evidence that collusion is more effective in a clock auction than under other auction formats. The average prices were lower for the clock format than for the uniform or discriminatory price auctions." (p. 2). According to the authors the chat protocols suggest that "the effect of the clock is to take out the price dimension so that bidders only have to reach an agreement in a single dimension, quantity" (p. 2). They also find that a clock auction leads to prices in the close neighbourhood of the reserve price and subsequent selling at higher prices in spot markets. See also Holt et al. (2008) on Goeree et al. (2009), and Goeree et al. (2010).

It is noteworthy that Holt et al. (2007, p. 31) also do not find the kind of advantages for clock auctions that Porter et al. (2009) report for the case of elastic demand curves ("narrow range of bidder values"). Holt et al. (2007, pp. 31–32) mention that there was a procedural difference between their experimental designs. Subjects in Porter et al. (2009) were put into a situation in which the demand structure (elastic or inelastic) switched randomly from one auction to the next within one session. In Holt et al. (2007) results are based on a comparison between sessions with a series of auctions using the same demand structure (elastic or inelastic).

A follow-up study by Burtraw et al. (2010) compares three formats, clock, uniform price sealed bid, and discriminatory sealed bid, in a rich environment with 6 bidders, permit banking, subsequent secondary markets, and compliance penalties, both with and without chat room collusion opportunities. In the no-chat treatment, clock auctions yielded lower revenues than sealed-bid uniform and discriminatory auctions. In the chat treatment, clock auctions yielded lower revenues than the uniform price auctions. In all formats, the presence of an opportunity to chat tended to reduce revenues.

The experiment reported in Shobe et al. (2010) also involved small numbers of bidders (6) but no chat opportunities. The environment, however, was stressful for auction performance in the sense that there was a "loose cap" environment in which the number of permits auctioned was a high percentage of demand quantity at the reserve price. The formats considered were uniform price and discriminatory sealed bid, and two versions of the clock, with and without ex-post demand revelation. Efficiencies were comparable in all formats, but auction revenues were highest with the discriminatory auction. This difference, however, diminished and ultimately went away by the final auction of a sequence of eight auctions.

Another recent experimental study by Mougeot et al. (2009) assesses the impact of speculators in an auction on the ability of bidders to collude. They compare an ascending-clock and a sealed-bid auction format with and without speculators. Speculators are essentially bidders who have no private value for the permits, and thus have only a common value, and will buy permits in the auction in order to sell them at a higher price in the secondary market. The experimental design is similar to Burtraw et al. (2010), but they only allowed pre-auction communication (chat room) and no communication between the rounds in clock auctions. In line with the results of Holt et al. (2007), the authors find that sealed-bid auctions lead to higher revenues, with less collusion compared to ascending clock auctions. The inclusion of speculators in the sealed bid-auction tends to increase the revenue further by making the auction more competitive. Interestingly, the allocative efficiency over all periods (including spot trading) is greater without speculators in both auction formats, thus leading to a trade-off between a positive impact of speculators in curbing collusion and maximising revenue compared to a negative impact on allocative efficiency.

Ockenfels (2009) is fairly clear about uniform pricing in various places (e.g., p. 110 as well as Section 3.2; see also Section 2, pp. 105 – 109)). He prefers a sealed-bid uniform-price auction to other auction formats. Apart from mentioning about ten arguments in favour of a uniform pricing rule, he also discusses the two prominent arguments against it (manipulability through collusive demand reduction and reduced price finding capability). He dismisses the manipulability argument for competitive markets and points out that functioning secondary markets a) will not need the price finding capability and b) will induce highly elastic demand functions that make collusive demand reduction very unlikely.

Ockenfels (2009) also points out that recent auctions in England, Ireland, and Hungary which applied uniform pricing have all been successful and that this pricing rule has established itself as the default option of choice.

Other experimental studies also suggest the uniform pricing rule as the appropriate pricing rule in permit auctions (e.g., Holt et al. 2007, Holt et al. 2008; Porter et al. 2009). However, Goeree, Offerman and Sloof (2009) compare the ascending clock auction (which implicitly implements uniform pricing) with a discriminatory auction setting and find that the ascending clock performs worse with regard to revenue and efficiency.

Our assessment: It is noteworthy that the three key auction formats in the experimental studies discussed above were all reasonably efficient. Therefore we do not see any reason to test additional pricing rules like discriminatory vs. uniform pricing.

Nevertheless, the choice of ascending clock auctions (and simultaneous clock auctions for that matter) has not been undisputed in the literature. The majority of auction designers seem to favour uniform-price sealed-bid auctions. Major concerns relate to the possibility of collusion. This point was acknowledged in the *White Paper* but ultimately dismissed based on the belief that the set of bidders would be "dispersed" and that the participation of financial institutions would be an additional safeguard. We therefore suggested testing uniform-price sealed-bid vs. clock auctions.

However, the results with regard to collusion by Holt et al. (2008) warrant careful attention. The risk of collusion seems to be the major disadvantage of the clock auction. That said, the experimental design of Holt et al. (2008) was strongly biased towards collusion. First, in most experiments subjects were permitted to collude, as the chat room was a crucial design feature of the experiment that participants were allowed to use without sanctions on agreements reached. One can imagine that in a real auction results might be different from competitive bidding if bidders were allowed to have a private meeting among themselves before the auction starts, particularly if there are no restrictions and penalties for collusive bidding behaviour. Second, in all experiments the number of bidders (6 per auction) was rather low. Our experimental design therefore did not offer a chat-room and involved a higher number of bidders (14 instead of 6 bidders).

2.2.2 Revelation of Aggregate Demand Each Round

In the context of FCC spectrum auctions, Kagel and Levin (2001) test the role of drop out information in ascending clock auctions and show that this information is important. Similarly, the Evans & Peck (2007) report argues that without revelation of aggregate demand at the end of each round, a (single-vintage) clock auction is theoretically equivalent to a sealed bid uniform price auction. Thus, from a theoretical perspective a sealed-bid auction and a clock auction in which aggregate demand is not revealed at the end of each round should result in exactly the same outcome.

Any difference between a clock and a sealed-bid auction should only unfold if at least some additional information is revealed. Despite the theoretical equivalence, bidders might behave differently in sealed-bid and in clock auctions even if aggregate demand is not revealed.

Holt et al. (2008, pp. 5–6) pay quite some attention to the issue of information revelation. They recall that in the 2004 Virginia NOx auction (summarized in Porter et al. 2009) aggregate demand was not revealed because of concerns that it would facilitate demand reduction.[7] Holt et al. also point out that "the decision of how much information to provide during the auction should be affected by opinions and evidence about the trade-off between the effects of additional collusion facilitated by the information and the added ability of the auction to track the market clearing price as a result of the added information" (p. 5). Additional experiments they ran indicate that more information does not improve price discovery but that this information facilitates collusion as well as demand reduction and in some cases even results in sharply reduced prices (p. 6). In the earlier study, Holt et al. (2007, p. 46) argue that, especially in clock auctions, the way to limit opportunities for collusion is to limit the information provided to bidders during and after the auction.

In the follow-up study Shobe et al. (2010) tested clock auctions with and without demand revelation in the one vintage setting. They do not find any significant differences with regard to revenue or efficiency which indicates that additional information has no impact.

Our assessment: On the one hand, demand revelation might facilitate collusion and demand reduction. On the other hand, some literature such as Kagel and Levin suggest that clock auctions with information revelation are generally considered to achieve outcomes which are closer to the Walrasian equilibrium (revenue and efficiency) than sealed formats.[8] The extent to which revelation of aggregate demand on balance facilitates or hampers efficient price discovery is an interesting question that has not yet been answered in a satisfactory manner, especially in multi-vintage settings. We therefore tested clock auctions with and without revelation of aggregated demand in each bidding round.

2.2.3 Proxy Bidding

With the success of consumer auctions on the internet, proxy-bidding has become a very popular auction feature. In single-unit auctions, for example, proxy bidding allows bidders to submit reservation prices that the auction system uses as limits in a virtual (English) auction: the computer bids on behalf of the bidder and at any time within an auction, the listed current price is the second highest proxy-bid (usually plus one increment). Due to the latter feature, the early literature (e.g. Roth and Ockenfels, 2002) has classified English auctions with proxy bidding as second-price auctions. This is also consistent with the strategic advice that platform operators such as eBay give to bidders: "When you place a bid, you enter the maximum amount you're willing to pay for the item."[9] With private values, the suggested bidding behaviour is a dominant strategy in a second-price auction and "if all bidders selected this form of bidding, the result would be equivalent to a uniform price, sealed-bid auction" (Holt et al., 2008, p. 7).

An open question, which has not been discussed in the literature, is whether the proxy bidding option should be implemented as an ex-ante choice, such that the choice of using the proxy option is definite (in the sense that bidders submit a sealed bid and cannot update this anymore), or whether an updating should be allowed during the auction even though a proxy bid function has been submitted.

[7] Note that this does not refer to the revelation of individual demand, but only to the revelation of aggregate demand after each round.
[8] See Chapter 4 for a definition of the Walrasian equilibrium.
[9] See http://pages.ebay.com/help/buy/automatic-bidding.html.

Our assessment: We do not see disadvantages from allowing proxy-bids. Advantages are that proxy-bidding reduces transaction costs and increases auction participation by allowing bidders to participate who may not be able to be present at the live auction. Proxy bidding might also smooth a migration from a clock to a sealed bid auction, as the sealed bid element is already implemented and only the possibility of updating has to be "switched off". A potential drawback is a higher complexity of the bidding process and possibly a more complex software interface. Since it is a special feature of the *White Paper* auction proposal, and since experiments evaluating this feature are not known, we provide for proxy-bids in the clock auctions in our experimental study, also in order to test how subjects cope with this feature.

Moreover, in the experiment we use the same user interface in both sealed bid and clock auctions in order to eliminate artefacts that only stem from the user interface. This improves the robustness of the experimental results. We recommended allowing subjects to update their demand at any time during the auction.

2.2.4 Auctioning Multiple Vintages

Holt et al. (2007) and Holt et al. (2008) did not experimentally test auctions of multiple vintages. The only study we are aware of which experimentally tests multiple vintage auctions is Porter et al. (2009). They find that, within an environment with a wider range of demand (average elasticity of 1.8), the simultaneous clock auctions perform better with regard to revenue compared to sealed-bid auctions and sequential clock auctions. However, no effects on allocative efficiency were found. Also, their experimental design included some specific rules (e.g. risk of discounting of banked permits) which do not apply for the Australian CPRS proposal. Therefore, it is not clear whether Porter et al.'s results can be applied to the Australian situation.

Holt et al. (2008) acknowledge the risk of price inversion when selling two vintages simultaneously in two separate uniform-price sealed-bid auctions. In this case, the price of the latter vintage could exceed the price of the earlier one, which is inconsistent with the assumption that an earlier vintage can be used later, and hence, has more convenience value. To fix this problem, Holt et al. (2008) suggest a "combined vintage auction" based on a "sorting" of bids. This bid sorting would prevent price inversions. We discuss the bid sorting algorithm of Holt et al. in Section 2.4.4 below and suggest a modification that fixes a remaining shortcoming.

If multiple vintages are auctioned simultaneously in a clock auction, automatic bid sorting is not necessary, because bidders can shift demand from one vintage to the other during the course of the auction. This will avoid price reversals.[10] Note, however, that shifting of bids may require additional micro rules that ensure consistency with the activity rule.

When selling two vintages sequentially, one has to decide whether to sell the earlier or the later vintage first. There exists some theoretical literature on this issue. Bernhardt and Scoones (1994) e.g. assume a model with private (partly unknown) values and show that auctioning the good with the more dispersed buyer valuations first yields higher revenues for the seller[11]. In the CPRS context, valuations of the earlier vintage are likely more dispersed as short-term abatement costs depend on the actual (possibly heterogeneous) situations of the companies whereas longer-term abatement costs depend more on the available technologies as well as overall market developments such as (relative) primary energy prices (e.g. prices for coal vs. prices for gas which hold for the whole industry) or the price of the permit in the secondary market.

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[10] With deferred payment arrangements, an inversion of the price structure refers to fundamental rather than nominal prices. Without knowledge of the bidders' internal discount factors, price inversions may not be observable.

[11] Similar results are obtained by Gale and Hausch (1992).

Another aspect regarding the sequence of auctions is that empirically declining prices are persistently observed in sequential auctions, a phenomenon commonly referred to as declining price anomaly or afternoon effect (Ashenfelter, 1989). Even though this effect refers to homogeneous goods, it is also of relevance for the Australian CPRS because (unrestricted) banking and (limited) borrowing will be allowed. So permits of different vintages are close-to-substitutes with the earlier vintage being somewhat more flexible with respect to its use and, thus, slightly more valuable[12]. According to McAfee and Vincent (1993), the declining price anomaly results in inefficient outcomes with positive probability. We conjecture that inefficiency will be even higher if more valuable items (earlier vintages) were auctioned later than less valuable items (later vintages) as the price anomaly might invert the theoretical price structure. Thus, we recommend auctioning earlier vintages first. This also seems to be best practice: both in RGGI and the Virginia NOx scheme, earlier vintages are auctioned first.

Our assessment: Simultaneous auctions of different vintages have only been tested by Porter et al. 2009, and it is not clear whether their findings also hold for the Australian CPRS. A major concern is the complexity of multiple simultaneous auctions which may deter bidders from participating. This was one of the reasons why the Virginia NO*x* auction was finally implemented as a sequence of clock auctions and not as the recommended simultaneous clock auction. We therefore employ additional experimentation of simultaneous ascending clock auctions (two vintages with a sealed-bid/proxy bidding option). We also test sequential vs. simultaneous sealed bid auctions (the latter with bid sorting) for two vintages. In order to compare the additional complexity of selling two vintages, we also test single vintage sealed bid and clock auctions. In line with the theoretical literature and current best practice we auction the earlier vintages first.

2.2.5 Double-Sided Auctions

Benz and Ehrhart (2007) show theoretically and experimentally that double-sided auctions are more efficient compared to single-sided auctions in private value settings when grandfathering and auctions are combined. Since net sellers of permits are excluded in pure single-sided auctions, scarcity is exaggerated and higher prices are likely. However, it is questionable whether the assumptions of the private values setting are appropriate, and it seems likely that the existence of a functioning secondary market might alter the results.

Holt et al. (2008) state that uncertainty about the totally available quantity in a double-sided auction makes collusion among bidders more difficult. A similar argument has been made in Evans & Peck (2007). However, this has not yet been tested experimentally.[13]

Our assessment: The question is whether recipients of free permits should be allowed to sell these permits in the government's auction. Notwithstanding the arguments by Ehrhart and Benz (2007), the issue might not be very critical if secondary markets exist at which permit holders can sell their endowment. Since functioning markets are unlikely to exist at the time the scheme will be introduced, double-sided auctions seem worth testing. There exist several ways to implement double-sided auction extensions: One option is that sellers submit individual reserve prices or supply functions. A second option is that sellers only submit the quantity to be sold and accept any resulting price. The latter would just imply a horizontal shift of the supply curve and, if announced, make no difference compared to a one-sided auction other than increasing the (known) number of permits to be sold.

[12] The proposed "deferred payment" of vintages affects their *nominal* price but not the *effective value* of a permit. Under a "deferred payment" scheme (nominal) prices of permits must be adjusted by the discount rate in order to allow for meaningful comparisons. This means that a higher nominal price of a later vintage does not necessarily indicate a reversal of real prices and therefore a low performance of the auction.

[13] Also, in the CPRS auction the total number of units to be auctioned will most probably be made known in advance of the auction and thus, there would be no uncertainty about the total available quantity to be auctioned.

Thus, only the former variant is worth experimental testing. Given that the Australian auction proposal envisages using the latter option we did not test a double-sided auction extension in our experimental study.

2.2.6 Reserve Price

From a theoretical perspective, optimal reserve prices are well understood. The relevant literature goes back to the early 1980s (e.g. Myerson 1981, Riley and Samuelson 1981). Theory predicts that appropriate reserve prices may prevent collusion, speed up the auction, and increase (expected) revenues (Engelbrecht-Wiggans 1987). McAfee and McMillan (1987), however, point out that inefficiencies are likely if not all items are sold.

The experimental literature on reserve prices, however, is not as rich with regard to permit auctions. Field studies in consumer markets support the theoretical predictions. Reiley (2006), for instance, finds in a field experiment that with high reserve prices the number of goods remaining unsold increases. Thus, in practical applications of permit auctions, the reserve price should be low enough for all permits to be sold.

When discussing how to set a reserve price in an emissions trading scheme context, one should distinguish whether an efficient secondary market for permits exists or not.

For the latter situation, RGGI may provide some insights. The scheme started with a fixed reserve price at US$1.85 which will be adjusted for inflation. Later on, the regulators have the option to move to a reserve price linked to market prices (e.g. to be set at 80 percent of the current market price). The first reserve price of US$1.85 was derived as 80 percent of a price predicted by RGGI specific modelling. Given the loose cap of the RGGI program, international permit prices such as for Certified Emissions Reductions were not valid reference points. As shown in Table 3 the reserve price was triggered in the December 2009 auction of the 2012 vintage auction, and not all allowances were sold.

If secondary markets exist, Ockenfels (2009) concludes, then all auctions should define a reserve price that is dependent on the price currently prevailing in those markets (p. 112(1)). In particular, the reserve price ought to be set as a percentage of the spot price prevailing in secondary markets shortly before the auction. He also argues that a high number of bidders, both on the supply and the demand side, is essential for an auction's success (p. 112(2)). Ockenfels' (2009) suggestions are generally in line with the EU ETS practice to date. Most auctions link the reserve price to the price in secondary markets (e.g. auctions held in Hungary and the UK). For the auctions in Germany, no reserve price is set. If there is not enough demand in any auction, it is closed and repeated 15 days later, unless the monitoring institution detects manipulative behaviour, in which case the German emissions trading authority can intervene and introduce dynamic price floors.

Another issue is whether reserve prices should be disclosed or not. Recommendation 6 in Holt et al. (2007) argues in favour of a publicly announced reserve price in general (but it may not be announced for the first auction), and this was followed in the RGGI design. In the EU ETS different practices exists: The reserve price was revealed in Hungary for the Phase 1 auction of EUAs, but other countries such as Ireland did not reveal it.

Ockenfels (2009) argues that the reserve price ought to be announced before the auction (although, in order to reduce attempts of strategic manipulation, the statistical price setting process itself should not be made public). Katkar and Reiley (2006) show that setting a secret reserve price in consumer online auctions lowers the seller's revenues.

One argument against revealing the reserve price is that it could serve as a focal point which facilitates collusion (Holt et al. 2008). The role of focal points in facilitating coordination is discussed in a more general context in Schelling (1958). This conjecture would be an argument for not revealing the reserve price in advance. Yet, to our knowledge, there is no empirical evidence that the phenomenon can be observed in auctions.

In the UK, the calculation procedure for the reserve price is announced, but without revealing the discount rates and target indexes. This approach was chosen in order to balance transparency and preventing the reserve price being used as a focal point for bids.

If the reserve price is triggered, a rule is necessary to decide what will happen with the unsold permits. Two options exist. First, unsold permits will be cancelled (which would be the incentive-compatible solution, but would also alter the cap). Second, unsold permits can be transferred to future auctions. This, however, might yield some bid distortions, as a failure of the auction will not reduce the supply of permits. Also hybrid rules (such as that 80% of unsold permits will be reintroduced in the market) are feasible.

Table 2.1 summarizes real-world examples of how reserve prices are set.

Table 2.1: Reserve price overview

Scheme	Reserve price	Calculation basis	Disclosure	When
Austria	yes	To be set by Ministry of Environment. The regulation only specifies that it needs to be oriented at the spot price.[a]	Yes	2 weeks prior to the auction
Hungary	yes	Closing forward price quoted by PointCarbon the day before the auction minus €0.90	Yes	Before (not sure when exactly)
Ireland	yes	Not revealed	No	n.a.
UK	yes	Discounted rate and markdown to the prevalent secondary market price before the close of the bidding window	No only calculation approach revealed	n.a.
Germany	no	n.a.	n.a.	n.a.
RGGI	yes	Option 1: 80% of price predicted by RGGI specific economic model (this reserve price was current in April 2010) Option 2 (later): 80% of the current market price	Yes Option 1: Announced in auction rules	Option 1: when auction rules published Option 2: not decided yet

Note: [a] For the March 2010 auction the reserve price was €10.95 (90% of the lowest spot price for EUAs in January to February 2010 of bluenext.eu. On 6 January 2010 it was €12.17).

Source: Various regulations

Our assessment: Setting a reserve price is important and common in permit auctions. The main advantage of aggressive reserve prices is that they reduce incentives for demand reduction. This increases both efficiency and revenues. So we agree with setting rather demanding reserve prices which will be determined in accordance with prices on an efficient secondary market (with some discount). For the first auctions (before an efficient secondary market exists) the reserve price needs to be selected to balance 1) the desirability of setting a high reserve price to reduce incentives for demand reduction with 2) the undesirability of setting a reserve prices so high that the efficiency of the market is hampered.

It is unclear from the literature whether the reserve price or the calculation method should be publicly announced. An experimental test of this issue is difficult because one would have to induce expectations of market participants about the Australian authorities' behaviour and possible price indexes. Therefore, no experimental testing of reserve prices is included in this study.

2.2.7 Parcel Size

We are not aware of any literature discussing the parcel size for auctions. Within the EU ETS the parcel size varies from 50 European Union Allowances (EUAs) in Austria to 1000 EUAs. The latter is the most common parcel size in Europe and was also used under the RGGI scheme (see Table 2.2). The parcel size seems to depend on the expected and desired number and size of the bidders.

Table 2.2: Minimum parcel sizes in various permit auctions

Country/Scheme	Minimum Parcel Size
Austria	50 European Union Allowances (EUAs)
UK	1000 EUAs
Germany	Spot 500 EUAs, Future: 1000 EUAs
Ireland	1000 EUAs (2nd Auction) 500 EUAs (1st Auction)
Hungary	1000 EUAs
RGGI	1000 Allowances

Source: Fazekas, F. 2008 and UK and German auction information, RGGI.

Our assessment: The minimum contract size (parcel size) does not impact the way the final allocation and prices are computed, neither does it increase computational complexity.[14] From the perspective of the bidders, the minimum contract size is relevant insofar as the demand at each price is rounded to the closest multiple of the minimum contract size. As a consequence, a large parcel size may slightly distort bidding behaviour and the relative distortions put a larger burden on small bidders. Thus, smaller contract sizes are better suited to serve the interests of all bidders. In financial markets small contract sizes are common. Thus, we recommended parcel sizes of 1 Australian Emissions Unit (AEU) equivalent to 1 t CO2e.

2.3 Timing and Frequency Issues

2.3.1 Auction Frequency

Ockenfels (2009) concludes that a final, theoretically or empirically grounded recommendation about an auction frequency can currently not be given (p. 111, column 2 and Section 3.3). The optimal frequency is a function of many factors, including the number of bidders, the volume of permits to be auctioned, the risk of collusion, the existence or emergence of a secondary market, the number of auctions conducted simultaneously, and the transaction costs, among others. Ockenfels (2009) argues that the final determination of the auction frequency ought to be based on secondary market data as well as trader surveys. The relation between auction frequency and secondary markets is also discussed in Mandel (2005). He states that when a perfect secondary market exists, a lower frequency of auctioning is preferable. Mandel suggests a high frequency of auctions during the early years of the scheme, which should be reduced over time when the permit market (spot and/or futures market) becomes more efficient.

[14] A smaller parcel size might lead to a linear increase of the number of bids.

Holt et al. (2007) proposed a quarterly modus which seems motivated by transaction cost considerations as well as prospective volume and regulatory risk of a delayed but similar federal auction permit process. RGGI followed this recommendation and runs quarterly auctions. In the first Phase of the EU ETS, most countries auctioned small amounts in only a few auctions (e.g. two auctions in Ireland). In the second Phase of the EU ETS, the UK runs eight auctions per year, omitting the months that are close to the surrender date (April and May) and those in which holidays are scheduled (August and December). The UK restricts auction participation in competitive auctions to approved primary participants (mainly financial institutions). Therefore, no analysis of the number of bidders in each auction is included here.[15] Austria has auctioned allowances twice a year in a competitive auction using the CLIMEX platform. Similar to the UK they also hold "non-competitive auctions" to serve smaller firms. In "non-competitive auctions" smaller firms can submit quantity bids which will be sold at the competitive auction price. Weekly auctions started in Germany in January 2010. The auctions are conducted by the European Energy Exchange (EEX) using their standard spot and future contracts.

Table 2.3: Experience with EU ETS permit auctions

Date	Contract / Vintage	Number of bidders taking part in auction	Demand (total amount of bids received)[a]	Supply (allowances)	Cover Ratio D / S	Clearing Price
AUSTRIA						€
12.03.2009	Non-competitive			5,050		11.65
16.03.2009	Competitive	n.a.	1,671,500	200,000	8.4	11.65
13.10.2009	Competitive	n.a.	893,250	200,000	4.5	14.23
23.03.2010	Competitive	13		200,000	4.2	12.78
GERMANY						€
05.01.2010	Spot	10	1,940,000	300,000	6.5	12.67
06.01.2010	Future	15	3,572,000	570,000	6.3	12.37
12.01.2010	Spot	6	1,350,000	300,000	4.5	12.71
13.01.2010	Future	13	3,746,000	570,000	6.6	12.81
19.01.2010	Spot	9	1,985,000	300,000	6.6	13.43
20.01.2010	Future	13	8,279,000	570,000	14.5	13.46
26.10.2010	Spot	9	1,770,000	300,000	5.9	13.27
27.01.2010	Future	10	3,866,000	570,000	6.8	13.67

Notes: [a] Demand is the aggregation of all valid bids, thus the demand at the lowest bidding price.
Sources: Austria: http://www.emissionshandelsregister.at/emission_trading/auction/ ;Germany: Jan Weiss, Presentation DEHST

[15] So far seven primary participants have been approved for the competitive auctions in the UK. For smaller compliance buyers a "non-competitive auction" has been introduced.

Table 2.4: Experience with RGGI permit auctions

Date	Contract / Vintage	Number of bidders taking part in auction	Demand (total amount of bids received)	Supply (allowances)	Cover Ratio D / S	Clearing Price
RGGI						US-$
28.09.2008	2009	59	51,518,087	12,565,387	4.1	3.07
17.12.2008	2009	69	110,270,643	31,505,898	3.5	3.38
18.03.2009	2009	50	78,784,413	31,513,765	2.5	3.51
	2012	20	5,003,680	2,175,513	2.3	3.05
17.06.2009	2009	54	80,307,812	30,887,620	2.6	3.23
	2012	13	3,476,064	2,172,540	1.6	2.06
09.09.2009	2009	46	71,022,363	28,408,945	2.5	2.19
	2012	12	2,389,794	2,172,540	1.1	1.87
02.12.2009	2009	62	74,338,415	28,591,698	2.6	2.05
	2012	8	1,119,300	1,599,000	0.7	1.86

Note: The reserve price was $1.85 per RGGI allowance at all auctions.
Source: http://www.rggi.org/co2-auctions/market_monitor

Tables 2.3 and 2.4 summarise the experiences with regard to the number of bidders and the ratio of bids to supply in different auctions. It can be seen that generally the number of bidders in less frequent auctions is higher (compare, e.g. Austria and Germany, with Austria auctioning only twice a year and weekly auctions being conducted in Germany; keep in mind though that Germany has about fourteen times higher greenhouse gas emissions compared to Austria under the EU ETS).

Our assessment: We agree with Ockenfels (2009) that there is no basis for a sound recommendation at this point. Given the EU and RGGI experience it seems that less frequent auctioning will increase the number of bidders. Since one cannot investigate optimal frequencies by means of a lab experiment, we do not experimentally test this issue.

2.3.2 Auction Timing

The CPRS plans early auctions, before the start of the scheme.

Ockenfels (2009, p. 111(2,3) and also p. 112 (3)) enumerates three reasons why early auctions are preferable (cost revelation, promotion of price finding and reduction of volatility and risk resulting from later auctions). He points out that electricity producers in Europe tend to sell their electricity well in advance of delivery (about three months to three years), resulting in a significant advance demand for pollution permits. He concludes that the optimal timing cannot be derived from theoretical or empirical work but has to result from an assessment of the likely demand configuration and experience.

The RGGI system started auctioning permits 3 months prior to the start of the scheme (first auction was held in September and the second in mid-December 2008, and the compliance programme started in January 2009). It seems that the auction has performed well in predicting the later market price of the permits (presentation by Bill Shobe, DCC October 2009).

None of the EU ETS member states auctioned allowances before the start of the scheme (January 2005). However, the reason seems to be more related to the fact that not all National Allocation Plans were approved by the Commission before the start of the EU ETS. Thus, the time pressure did not allow for early auctions, but there was no reason against early auctioning.

Our assessment: In line with the arguments above, that auction timing cannot be investigated by lab experiments, we do not test this question in our experiment.

2.3.3 Advance Auctions

In addition to early auctions, advance auctions are auctions which sell future vintages in order to facilitate spot trading of vintages which complement derivative markets. There is some literature on the value of future markets (e.g. on the value of hedging), and some of these papers focus on emissions trading, e.g. Baldursson and van der Fehr (2005) and Ehrhart et al. (2005). The latter specifically sees a value in "auctioning off prior to the start of the commitment periods, (as) this may generate good price signals for the future scarcity of allowances and contribute to lowering abatement costs."

In the RGGI auctions the number of bidders was lower in auctions of future vintages (3 years in advance) compared to spot auctions. In addition, the prices in those advance auctions were lower than could be rationalized by the "cost of carry"; most likely they reflected political uncertainty about the future of the RGGI scheme in light of the potential introduction of a Federal Emissions Trading Scheme in the US.

Another issue in this context is how many vintages should be auctioned in advance. The current CPRS proposal foresees auctioning vintages up to 3 years in advance. This is in line with recommendation 5 in Holt et al (2007), who propose that future allowances are made available four years in advance of their vintage. It is also in line with the call of European utilities that argue for early auctions of allowances in the EU ETS in order to be able to continue hedging their price risks stemming from their forward power sales. As mentioned above, electricity producers in Europe sell electricity up to three years in advance (Ockenfels 2009). The Australian National Electricity Market works differently, with no contracts for physical delivery, but with an extensive financial market in derivatives, including futures and options. According to the Australian Energy Regulator (2009), there is little trade in derivatives with end dates of more than two years after the trade date.

In addition there is an open question as to how often advance auctions should be held. The *White Paper* foresees annual auctions for each future vintage. We are not aware of any academic literature that takes a position on how often advance auctions should be held and whether advance auctions should be held in conjunction with spot auctions. Auctioning current and future vintages at one event is current practice in RGGI and at the Virginia NOx auction. For example, RGGI auctions small amounts of future vintages at each quarterly auction event. In Virginia, the 2004 NOx allowances were auctioned in the morning and the 2005 allowances in the afternoon. However, in Germany spot and futures are auctioned one to several days apart (see Table 2.3).

Our assessment: Auctioning future vintages jointly with the current vintage reduces transaction costs for all participants. Note that according to the *White Paper*, there might be up to five auctions at one event (one current vintage auction, three future vintages auctions, and the wrap-up auction for the previous year vintage). We believe bundling of future vintage auctions to be a sensible position, as this may increase the number of bidders in the future vintage auctions and increase management attention. As mentioned before, whether spot and future vintage auctions should be held simultaneously or sequentially requires experimental testing. Therefore, the auctioning of two, partly substitutable vintages is part of our experimental study.

2.3.4 Deferred Payment Arrangements

The Government has announced that transitional deferred payment arrangements will apply to future-vintage auctions held for the first two years of the scheme. Under those arrangements, purchasers will be required to pay a 10% deposit. The details of the arrangements including forfeiture will be set out in the Ministerial determination of auction procedures.

Holt et al. (2007, see recommendations 9 and 10 that speak to the issues) emphasise the importance of financial pre-qualification and the need to be able to treat accepted bids as binding contracts. The latter is especially important for ensuring that purchases in an auction which allows for deferred payment will not be seen as buying an *option* for a permit, rather than entering into a forward *contract*.

In the European Union, a somewhat similar discussion is taking place under the heading of "early auctioning" and "auctioning futures/forwards". The "early auction" discussion was initiated by power companies worried about a shortage in permit supply for future contracts in Phase 3 of the EU ETS (Centre for Clean Air Policy, 2009). "Auctioning futures/forwards" were cash flow arguments. So far a draft EU Auction Regulation has been released (European Commission 2010) which includes "early auctioning" and "auctioning futures/forward"options for member states. Germany is auctioning future contracts in Phase 2 with a delivery date in December of the respective year via the European Energy Exchange. Those future contracts are auctioned weekly from January to October each year. The number of European Union Allowances auctioned at each future auction is 570,000 EUAs which is high compared to the 300,000 European Union Allowances which are auctioned as spot products at each auction (Deutscher Bundestag 2009). Auctioning a higher number of future products reflects the higher demand for future products (see Figure 2).

Our assessment: The possibility of strategic defaults would need to be tested in a completely different experimental framework from the one we set up for the experimental testing of other auction design features. However, the option of auctioning allowances for future delivery (as in Germany), facilitated by using a clearing house, instead of allowing deferred payments seems to be worth considering. If permits were not to be delivered before the deferred payment is made (as is currently proposed in Australia), trading of these permits would be difficult. If participants do not settle early, secondary trading of such permits would be confined to the derivatives market under uncovered forward short selling arrangements.

2.4 Operational Features

2.4.1 Participation, Deposits and Settlement

The Australian auction proposal foresees no restrictions in participation at the auctions. Deposits and having a registry account are the only requirements. This is in line with recommendation 9 in Holt et al (2007) and RGGI's implementation: no participation limitation but 100% financial assurance is required. The maximum amount one buyer could bid for in the RGGI scheme was 25% of the auctioned amount of each vintage.

The auctions of the EU ETS use similar practices (Fazekas 2008): unlimited participation and deposits are required. In Phase 2, the UK has restricted the competitive auctions to financial institutions, and Germany has transferred the auction implementation to an existing exchange. Therefore, no special rules for financial assurances are required in the UK and Germany.

Ockenfels (2009, p. 113; much of section 3.6.) discusses the issue of appropriate deposits and settlement dates. A deposit that is set too low (and a settlement date that is delayed too long) may invite strategic defaults. Similarly, a deposit that is set too high might reduce the number of bidders. Ockenfels discusses the examples of problematic deposit and settlement requirements (Ireland too low, too late, and Hungary too high) and recommends shortening settlement period to the minimum, possibly even the same day.

Our assessment: Universal participation is rated positively, as it increases the number of bidders. By the same token, as also stressed in recommendations 9 and 10 in Holt et al. (2007), financial pre-qualification and treating accepted bids as binding contracts are imperative. In line with our assessment above we consider these issues as practical implementation details which do not need to be tested experimentally.

2.4.2 Publication of Auction Results as Soon as Possible

The information which is revealed after the auction varies between the different auctions. The RGGI publishes a market monitoring report around two days after each auction, which includes the number of bidders, the category of bidders ("compliance entities" and "non-compliance entities", environmental/individuals), their respective shares, and the quantity of allowances awarded to bidders (anonymous). RGGI also publishes minimum and maximum bid prices as well as averages (median and mean) and the clearing price.[16]

The EU ETS follows less detailed practices (e.g. they do not differentiate between compliance and non-compliance entities, and do not report absolute quantities). For the UK competitive auction, a monitoring report is published after each auction. The report includes the share of direct participants to indirect participants, the aggregate of all valid bids at the lowest price, and the auction clearing price. The German auction provides information about the number of bidders, the aggregate of all valid bids at the lowest price, the minimum and maximum bid prices as well as averages (median and mean), and the clearing prices.[17]

Our assessment: There is no reason not to reveal auction results as soon as possible after the auction. Publication should be as comprehensive as under RGGI, including the number of bidders, the category of bidders ("compliance entities" and "non-compliance entities", environmental/individuals), their respective shares, and the quantities of allowances awarded to bidders (anonymous). In addition, minimum and maximum bid prices as well as averages (median and mean) and the auction clearing prices should be published. It would be valuable to also include information on the aggregate demand at the reserve price (if revealed and applicable).

2.4.3 User Training

Training of users for the auction is very important and seems to be best practice (see RGGI and Germany as examples).

Our assessment: We do agree that users should be offered the opportunity to become familiar with the auction setup. However, we do not see this as a priority for our experiments as we believe user training should be offered in any case. Still, our experiments may indicate the extent of learning in different auction formats.

2.4.4 Micro Rules

Each auction type requires a set of micro rules which define the concise mechanics of the auction. In this section, we discuss micro rules regarding pricing, the allocation of excess supply, activity requirements, switching rules, and bid sorting. The first two rules apply for both clock and sealed bid formats. Activity and switching rules are relevant for clock auctions, whereas bid sorting can only be applied in sealed bid auctions.

Pricing: lowest accepted bid vs. highest rejected bid

In this study we only consider uniform pricing schemes. Uniform pricing means that all successful bidders pay the same price, for all units of the item they acquire[18].

[16] See http://www.rggi.org/co2-auctions/market_monitor for more details.
[17] See http://ec.europa.eu/environment/climat/emission/auctioning_en.htm for references to the different auction schemes under the EU ETS Phase 2.
[18] Note that uniform pricing only refers to the prices of the units of one item (vintage). In a multi-item extension, different vintages may well sell for different prices.

However, even under uniform pricing two different pricing rules can be applied, in both sealed bid and clock auctions. The first pricing rule states that the lowest price of all winning bids (also referred to as lowest accepted bid, LAB) determines the price which all winning bidders have to pay. Under the second rule, the final price of the auction is given by the highest price of all losing bids (also referred to as highest rejected bid, HRB). Sujarittanonta and Cramton (forthcoming) discuss the two versions extensively. They focus on auctions where bidders have unit demand, and argue that – from a theoretical perspective – HRB outperforms LAB. In particular, the authors highlight the efficiency of the HRB format. Interestingly, however, in an experimental study of auctions with two bidders and unit demand, Cramton et al. (2009) find that LAB yields higher revenues, and conclude that this might be a reason for the frequent use of this rule. These findings also highlight that actual behaviour of bidders might differ from theoretical expectations.

Due to the focus on only two bidders whose demand is restricted to only one unit each, the above papers do not fully apply to emission permit auctions with their large number of bidders and multi-unit demand. The more items are auctioned and the more bidders participate, the lower will be any difference between the two formats: If the number of items is large and price steps are discrete, then it is unlikely that at the end of the auction demand will exactly equal supply. This, however, is the only case in which the two rules lead to a different price. In all other cases, the lowest accepted and the highest rejected bid will be equal. If, additionally the number of bidders is large, then the probability that a bidder will impact the closing price by her bid is small. Thus, bidding strategies under the two pricing rules will be very similar.

Our assessment: Lowest price of all winning bids (LAB) is applied in central bank auctions, spectrum auctions as well as consumer auctions on the internet. It is thus by far the more common format. We are not aware of shortcomings of this rule in large scale auction applications. Thus, we do not see the necessity to test this rule against alternatives, and applied LAB in all auctions in the experiment.

Rationing of bids: balancing supply and demand

If price steps are discrete and the number of auctioned items is large, then aggregate demand will typically be larger than the supply at the closing price of the auction (note that the auction cannot close if demand is smaller than supply). Consequently, a tie-breaking rule is necessary to determine which of the bids at the closing price are fully served and which are rationed. Several options are possible. These options include giving priority to the bids which were submitted earlier, selecting bids to be served by a random method, or serving bids at the closing price proportionally. We are not aware of studies that explicitly address this issue for auctions of many items. However, we note that the latter two principles in particular are similar, as a proportional allocation is just the expected outcome of a random allocation.

For efficiency reasons it is important that particularly those bids are served where the bidders' values for the items are *higher* than the closing price. Note that at one price step above the closing price demand is smaller than supply, so this demand can and should be fully served. Any rationing of bids only relates to the remaining demand at the closing price after higher bids have been served. The supply not already allocated in the first step (called excess supply in our experiment) needs to be distributed over this remaining demand.

Proportional rationing of these bids (i.e. proportional allocation of the remaining supply or the remaining demand) is very common, particularly in financial markets (e.g. IPOs) or central bank auctions (e.g. Term Auctions of the U.S. Federal Reserve). A potential reason is that it appears to be the fairest approach. Deviations might be considered as discrimination and could be subject to legal objections.

A further, rather technical issue is the rounding of fractions smaller than the minimum contract size. Again, fractions could be resolved on a random basis: first the integer shares of the fractions are served, and any still remaining supply is randomly allocated among the remaining demand. Another possibility is to apply a particular rounding rule[19]. In the experiment we used the largest remainder method (also known as Hare-Niemeyer rule and, commonly applied in proportional representation voting). Note that the different rules for resolving fractions of the minimum contract size will not result in differences in efficiency, revenue, or bidder surplus if marginal bids reflect marginal valuations. In this case, bidders are indifferent whether marginal bids are served at the price of these bids or not.

Our assessment: We consider proportional rationing as best practice and consistently apply it in the experiment.

Activity requirements:

Activity rules were introduced with the early FCC spectrum auctions. Milgrom (2000) argues in his assessment of the first simultaneous ascending auction for radio spectrum in US in 1994 that activity rules are important to restrict wait-and-see strategies.

Typically an activity rule requires that the total demand of a bidder may not increase from round to round as prices are increasing. Thus each bidder maintains a number of so-called bidding rights (her eligibility) which limit the total number of units a bidder might bid for in a particular round. If the bidder decides to bid on fewer units, the bidding rights are reduced accordingly. However, the literature mainly just stresses the need for the existence of a proper activity rule, rather than recommending particular designs. In fact, many actual auctions even apply rather weaker versions with required activity levels far below 100% (e.g. FCC spectrum auctions or German 4G spectrum auction).

Our assessment: Weak activity rules (i.e. rules which require activity levels below 100%) are appropriate if different items sell in chunk sizes of different values, i.e. when the units of different items are not or hardly comparable. Radio spectrums in different frequency ranges may serve as an example. This inhomogeneity does not hold for emissions permits which are measured in equal quantity units (AEUs). Thus, in the experiment a straightforward activity rule was applied which did not allow bidders to increase their total demand from one round to the next.

Flexibility in simultaneous multi-vintage clock auctions: switching demand

The principle idea of simultaneous auctions is to give bidders the flexibility to switch between the vintages. Effectively this implies that a bidder might wish to increase her demand for one vintage. Thus, a relaxation of the activity rule is required. The relaxed activity rule allows a bidder to increase her demand for one vintage if at the same time she decreases her demand for another vintage by at least the same number of units.

Generous switching, however, is not without pitfalls. Any switching rule must obey two basic conditions: First, aggregate demand must never fall below total supply if at any time during the auction aggregate demand was at least as high as supply (efficiency requirement), and second, a bidder may never obtain more items in total than the activity rule allows (eligibility requirement).

For illustration, consider the following simple example of an auction of two vintages A and B, with supply quantities of 100 units for A and 80 units for B. Assume that at a price of $9 for each unit of vintage A, a particular bidder demands 30 units of vintage A, and the current total demand for this vintage is 110 units (including the considered bidder's demand).

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[19] See, for example, http://www.federalreserve.gov/monetarypolicy/taf.htm for a description of how the U.S. Federal Reserve resolves partial bids.

Additionally, the bidder bids for 10 units of vintage B in this auction round. Hence, she demands a total of 40 units in this round. Since the current total demand for vintage A exceeds the supply of this vintage, the unit price of vintage A increases by an increment step of $1 from $9 to $10 in the next round. Assume that at this price (only) the considered bidder plans to change her demand for vintage A compared to the price before (i.e. $9) by shifting 20 units of her demand from vintage A to vintage B.

Although the bidder is still demanding a total of 40 units for the two vintages (i.e. 10 units of A and 30 units of B), the total demand for vintage A decreases to 90 units, and thus the auction for this vintage intermittently stops at $10, as at this price the demand for vintage A no longer exceeds the supply. Now assume that the auction ends with this constellation. The total demand of 90 units for A will be fulfilled, and the bidder receives 10 units at a unit price of $9 (i.e. the last price at which the demand meets or exceeds the supply). Furthermore, assume that the bidder's demand of 30 units of B is also completely met at the end of the auction. Since at the price of $9 for A the demand exceeds the supply, the efficiency requirement states that the total supply of 100 units of A must be sold. Hence the remaining 10 units of vintage A need to be allocated. Since the considered bidder is the decisive bidder for vintage A, whose demand switch from A to B induces the excess supply and thus the end of the auction for vintage A, the excess supply of A should be typically allocated to her. Assigning the bidder a total of 50 units, however, is not admissible, because she would then receive more units than the activity rule allows. As a consequence, demand switches have to be restricted such that this case cannot occur and the efficiency criterion is met at the same time.

A natural approach which stems from the analogy of simultaneous ascending auctions is to announce "temporarily assigned quantities" (similar to "standing high bids" in simultaneous ascending auctions). Any remaining demand would be considered as free bidding rights, and a bidder would be free to decide on the vintage for which she would like to use these rights. Thus, a bidder would be (ex-ante) restrained to switch not more than an amount equal to his free bidding rights. Obviously, the rule ensures both the efficiency and the eligibility requirement. Moreover, the rule is easy to understand and has been applied in numerous spectrum auctions around the world. So it seems appropriate for an application in the CPRS auctions.

The focus of the experiment was on a comparison of different auction types. In order not to distort observations by differences in the user interface, very similar interfaces with the same visual appearance were used in all auction designs. However, this ruled out the possibility to display temporarily assigned quantities. Thus, in the experiment we employed a different approach which allowed (ex-ante) unrestricted switching (within the limits of the bidders' respective eligibility constraints). If necessary, after the end of a bidding round, switches were (ex-post) adjusted, i.e. proportionally reduced such that both the efficiency and the eligibility requirement were met.

We are not aware of other studies which have investigated alternative switching rules or that such rules have been applied in practice.

Our assessment: For experimental design reasons we aimed to avoid differences in the user interface between auction formats. As displaying temporary assigned quantities was not feasible within the same layout, we decided to allow for unrestricted switching. The participants in the experiment were told that if the total switches resulted in a drop of aggregated demand below the supply, the switches were automatically reduced on a proportional basis. Our ex-post adjustment allowed maximum flexibility for participants and ensured that the activity rules were obeyed. See Appendix for details on the implementation.

Bid sorting

In an emission trading scheme permits can typically be transferred forward into future periods without restriction, but the reverse is not true.

All other things equal, this implies that earlier vintages cannot be worth less than later vintages, and should thus sell at higher prices.

Standard rules of non-combinatorial sealed bid auctions of different items do not take this relationship between vintages into consideration. Consequently, there is a possibility that non-combinatorial sealed bid auctions result in prices which violate the value relation (i.e. the price for a later vintage is higher than the price of an earlier vintage). Such a constellation is likely to be inefficient, but can result from purely rational bids.

Holt et al. (2007, addendum) discuss this issue and suggest an algorithm for sorting bids which avoids reversed price structures. However, their algorithm does not avoid inverted allocations in the sense that lower bids are served with permits of higher value[20]. See the Appendix for technical details of the rule.

Our assessment: In the experiments, we follow the standard assumption that earlier vintages are worth at least as much as later vintages, and induce valuations accordingly. For this reason, we also apply a modified bid sorting algorithm which avoids both inverted prices and allocations. Details can be found in the Appendix. However, such a bid sorting algorithm is incompatible with the proposed design of the Australian CPRS. Due to transitional deferred payment arrangements, nominal prices may not reflect the order of values. With an ambiguous order of values, bid sorting algorithms as used in the experiment may not be appropriate and therefore cannot be applied.

2.5 Summary

The literature review indicates that the proposed auction design (simultaneous clock auctions with proxy-bidding option) has not been used in previous permit auctions. Most of the permit auctions conducted in the EU or US schemes have applied a simple sealed-bid uniform price format. There is only one experimental paper (Porter et al. 2009) which has tested multiple vintage uniform price auctions (sealed bid, sequential clock and simultaneous clock) in the context of the Virginia NOx auction. However, proxy-bidding was not part of the design, and some other features may restrict the transferability to the proposed CPRS auction. Given these findings and the assessments above on specific auction design parameters, we test the following auction design issues:

- Multiple uniform-price sealed bid auctions with bid sorting
- Simultaneous vs. sequential clocks
- Revelation or non-revelation of total/ excess demand

[20] Cf. Example 1 in Holt et al. (2007, addendum, p. 10). In the example, two vintages, 2009 and 2012, are auctioned. After bid sorting, the 2009 permit sells for $3 and the 2012 permit sells for $2. So the later vintage sells for the lower price. However, there is one bidder who has bid $4 for a 2012 permit and another bidder who has bid $5 for the same vintage. Due to the bid sorting, the first bidder receives a 2009 vintage at $3 and the latter bidder receives the 2012 permit he has bid for $2. So the lower bid is served with a more valuable and a more expensive good.

3. Design and Conduct of Experiments

3.1 Experimental Design

As a result of the joint workshop between DCC and the project team in October 2009, the two most important questions about the carbon permit auction design identified to be investigated by the experiments are:

- Should the auction follow a sealed-bid approach or should it be implemented as an ascending price clock auction?
- Should multiple vintages be auctioned off simultaneously in an integrated auction procedure or sequentially in several one-vintage auctions?

3.1.1 Auction Type: Sealed Bid vs. Clock, Aggregate Demand Revealed or Not Revealed

In line with the *White Paper,* the discussion in the workshop highlighted that the CPRS auctions will be non-combinatorial and apply uniform pricing. This implies that quantity bids are not submitted as bids over packages of different vintages, but separately for different vintages (non-combinatorial), and that all successful bidders pay the same price per unit (uniform price). However, within this class of auctions there are several types to be considered. First, the most prominently used auction format in carbon permit allocations around the world is a uniform price *sealed bid format*, in which bidders submit their demand functions in advance, and the auctioneer determines the price and allocation based on those individual demand functions.

The second format which was discussed in the workshop is the *ascending price clock format*, a dynamic auction which starts at a low price that increases over time, and bidders submit their demand at the current price in each biding round. An open question is whether in such a format the aggregate demand at each price step should be revealed or not.

Clock auctions with revelation of aggregate demand after each bidding round (hereafter called open clock auctions) are said to have better price discovery properties than sealed bid auctions. Good price signals are important as they are the basis for companies' investment decisions and are thereby a prerequisite for innovation. However, the open format of clock auctions allows bidders to update their information about the overall market structure and their own market power. Thus, open clock auctions are more vulnerable to the problem of demand reduction. Demand reduction will not only lead to lower prices but might also result in lower efficiency. Thus, the advantages and disadvantages of open clock and sealed-bid format have to be carefully balanced against each other.

In the single vintage case, not revealing the aggregate demand in the ascending price clock auction makes this format strategically equivalent to the sealed bid auction. (In a sealed-bid auction, bidders define their demand at each price assuming that at lower prices aggregate demand exceeds supply – this is exactly the information that is revealed in a clock auction by the fact that the price clock ticks forward.) However, a clock format might be easier to understand, as bid functions have to be submitted only bit by bit, and not fully in advance.

In the case of auctioning multiple vintages simultaneously, a clock auction which does not reveal aggregate demand provides a little more information than a sealed bid auction, and allows bidders to switch demand from one vintage to another. Thus, bids in this format can be contingent on information on price differences which is not available in a sealed-bid format.

To support the selection of an appropriate auction type for the Australian carbon permit auctions, it was agreed to examine experimental evidence on the relative performance of the two formats in different scenarios. The auction types to be tested are "uniform price sealed bid", "ascending price clock with aggregate demand revelation" (also called open clock auction) and "ascending price clock without aggregate demand revelation" (closed clock auction).

3.1.2 Auctioning Multiple Vintages: Simultaneous vs. Sequential Auctions

If multiple vintages of carbon permits are to be auctioned, an important question is whether those vintages should be auctioned off simultaneously or sequentially. Auctioning sequentially means conducting a series of single vintage auctions, one for each vintage. The order usually proposed and assumed in the literature is to start with the earliest vintage (see discussions in Chapters 2 and 5).

An alternative procedure would be to auction different vintages simultaneously. A potential advantage of a simultaneous clock auction is that it allows bidders to better coordinate between vintages, as they can switch their demand from one vintage to the other depending on current prices in the auction. A disadvantage is that simultaneous clocks add a considerable amount of complexity to the auction procedure. Complexity increases in terms of the information bidders have to process, as well as in terms of sophisticated additional "micro rules" (e.g. activity rules, switching rules, ex-post corrections, see Section 2.4.4).

For these reasons regulators seem to be generally hesitant to use simultaneous clock auctions (e.g. Virgina NOx auction, see Porter et al. 2009). Also, the Department indicated at the workshop that a simultaneous auction design with multiple vintages may be difficult to promote due to its complexity. So auctioning more than two vintages simultaneously may not be advisable in this context.

To test the trade-offs between simultaneous and sequential auctions, it was agreed to test three different market environments in the experiments: a single vintage scenario, a scenario with two vintages auctioned simultaneously, and a scenario in which two vintages are auctioned sequentially.

3.1.3 Existence of a Secondary Market

The relative performance of an auction type might depend on the existence of a functioning secondary market. In particular, trading in secondary markets before the auction provides important price signals that make the relative price discovery advantage of a clock mechanism obsolete. On the other hand, the unknown future market price adds a common value aspect to the value of the permits, as they can be bought and sold also after the auction. This turns the auction into a "guess the market price" game.

In order to test the robustness of an auction type against the existence of a secondary market, we included a treatment that allows for trading among bidders, after a simultaneous 2-vintage auction.

Note that we do not incorporate the price signal features of preceding secondary markets in the experiment. First, this would have required a more complex design, spanning several trading and auction periods (see also discussion below), and second we focus in this study on the *initial* auction design for Australian carbon permits, where functioning pre-auction secondary markets may not exist.

3.1.4 Experimental Treatments

The discussion above yields the following 3x4 factorial experimental design.

Table 3.1: Experimental treatments

Treatments		Auction type		
		Sealed bid auction	Clock auction without information revelation of excess demand	Clock auction with information revelation of excess demand
Market complexity	1 vintage	T3	T2	T1
	2 vintages sequentially	T11	T9	T8
	2 vintages simultaneously with bid sorting	T10	T5	T4
	2 vintages simultaneously, plus secondary market	T12	T7	T6

Based on the literature review and on workshop discussions, the number of bidders in each experimental observation was set to 14. Note, that this is a large group size compared to other experimental studies of such auctions, which have mostly involved about 6 bidders. In order to gain even more insights into the effects of large bidder numbers on the auction, it was agreed to add one treatment that tests the eventually recommended design (clock auction with revelation of aggregate demand, multiple vintages auctioned off sequentially, see chapter 6) in a market environment with a large number of bidders. Thus, Treatment 13 is a replication of Treatment 8 with 42 traders, i.e. with a bidder group three times the size of our regular trader groups in the experiment.

3.1.5 Other Experimental Features

Proxy Bidding

It was agreed that any type of clock auction considered should employ a *proxy mechanism*, which allows bidders to submit a sealed bid function in advance (such that they are not required to attend the auction). Bidders should be able to revise their bid function (for the remaining rounds of the auction) at any point of time. This hybrid format has additional advantages: it can be easily transformed into a true sealed bid format by dropping the possibility of revising the bid function, and it facilitates a simple implementation of intra-round bidding by allowing bidders to specify their bid function not only over the pre-defined price steps but over any price steps they wish.

Thus, the clock auctions implemented in our experiments allow for proxy bidding (except for the learning phase in the first two auctions of each session, see below).

Micro Rules

While the specification of micro rules (activity rules, allocation of excess supply in the case of overshooting, switching rules, stopping rules, bid sorting) is an important aspect of this study, it has to be recognised (and was also agreed in the workshop) that the specific micro rules to be employed in different scenarios are given and fixed.

Also, the more complex switching/stopping rules and bid sorting only apply to simultaneous clock and simultaneous sealed bid auctions, respectively.

- The *activity rule* will not allow total demand to increase over all vintages when prices are rising. For single vintage auctions this rule implies that bidding quantities for the single vintage cannot increase with increasing prices. For auctions of multiple (i.e. two) vintages the rule implies that the total demand of a bidder (the sum of demanded quantities over all vintages) cannot increase with increasing prices. However, as long as their total demand does not increase, bidders may switch their demand between individual vintages according to the *switching rule* stated below.
- *Excess supply* at a clock auction's last round is allocated proportionally to the unfulfilled individual demands in the second-to-last bidding round. In that case, bidders pay the price of the second-to-last bidding round for all their allocated items (uniform pricing). A respective rule is applied for the sealed-bid auctions.
- The *stopping rule* states that a price clock stops as soon as demand is equal or lower than supply at a given price. If, however, aggregate demand increases again (due to demand switching between vintages according to the *activity and switching rules*), the price clock might start to tick forward again. The auction is over once the price clocks for all vintages have stopped.
- The *switching rule* states that demand can be switched without restrictions between multiple vintages as long as the *activity rule* is met and the demand does not drop below supply for any vintage due to switching.
- The *bid sorting rule* is applied in sealed bid auctions if there is a monotonic relationship between the fundamental values of different vintages (i.e. if one vintage is strictly more valuable than another). In the experiment, permits for earlier vintages (item A) were at least as valuable as permits for later vintages (item B). Bid sorting ensures that in a simultaneous sealed bid auction vintages of lower value will not be sold at a higher price than vintages of higher value. Note, however, that with the transitional deferred payment arrangements proposed for the early years of the CPRS, the relation of nominal values between vintages is not monotonic, and therefore bid sorting (of nominal bids) might not be applicable.

For a discussion of those rules see Chapter 2, for a mathematical or algorithmic specification of the above rules for an actual implementation see Chapter 6 and the Appendix.

In the experiment, we employed the above rules in the corresponding experimental treatments, and thereby tested their robustness and whether they have unpredicted effects on bidding behaviour.

Time Horizon and Complexity

The workshop included a discussion of the complexity that is desirable and feasible in a laboratory experiment. The experimental setup could involve a complex design spanning several years of auctions over time, involving features such as banking of permits or pre-auction secondary markets. Or the experiment could use a simple one-shot design, which only tests one auction (plus a subsequent secondary market in some treatments), which then could be repeated several times in order to facilitate learning and to collect more observations. In any of these scenarios one could additionally incorporate product markets, abatement investments, compliance checks and penalties, etc. into the experimental environment.

For reasons of experimental control and in order to facilitate data analysis it was decided in the workshop to employ a repeated one-shot design. For the same reasons product market decisions and abatement investments were not included as endogenous choices, and the experiment involved neither compliance checks nor penalties.

Rather, all those features external to the actual permit allocation auction were represented by induced valuations. Each bidder received a monetary valuation for each possible bundle of permits that could be purchased. In a sense, these valuations represent the value of permits given optimal choices in product markets and abatements investments etc.

Market Size

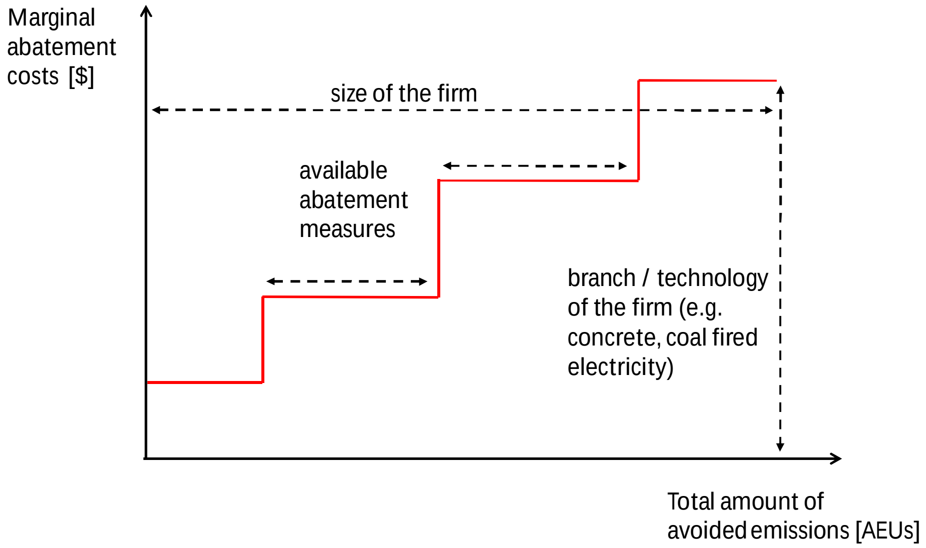
In the experiment we had 14 bidders in each auction. This number was determined by the size of the experimental laboratories utilized in this study. Note, however, that to the best of our knowledge this is the largest group size used in laboratory experiments on permit auctions to date. As described above, in Treatment 13 we tripled the number of bidders to test for robustness against market size.

Demand Structure and Bidders' Valuations

Bidders in each auction were heterogeneous in their valuations ("roles"). The sets of valuation functions (demand structures reflecting marginal abatement costs) differed between sessions, such that we employed 6 different demand structures, representing different levels of skewness and concentration of the prospective permit market. The same 6 different demand structures were used in all treatments.

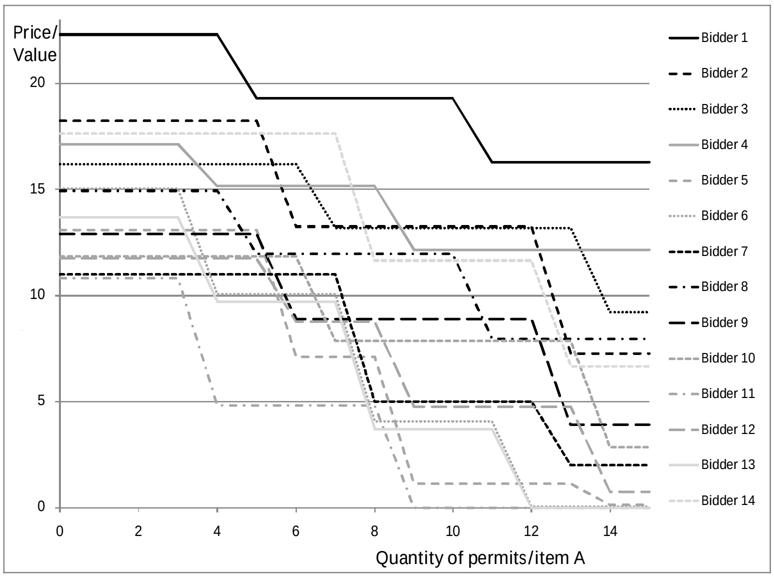
Figure 3.1 illustrates how marginal abatement cost curves were derived. The height of the steps of a marginal abatement cost curve represents the costs for each potentially employed abatement measure, and the length of a step represents the amount of emissions which can be avoided using that particular measure at those costs. The length of the complete curve represents the size of the firm: obviously, a firm maximally can only avoid as many emissions as it currently emits.

Figure 3.1: Individual marginal abatement cost curve



For the experiment, marginal abatement cost curves were generated by randomly drawing firm sizes as well as number and height of abatement cost curve steps. Based on the generated abatement cost curves, we derived bidders' corresponding permit demand curves in the permit allocation auction. As an example, Figure 3.2 shows the resulting marginal value functions for each of the 14 bidders in our experimental demand schedule 3.

Figure 3.2: Example - Marginal value functions in experimental demand schedule



In the two-vintage treatments, the separate marginal value function for item B was either the same as the marginal value function for item A (discount factor = 1), or was proportionally discounted by a factor of 0.8 (see also below). To derive valuations over A-B-bundles we modelled asymmetric substitutability on top of those separate marginal value functions. In other words, we specified that item A units (current vintage) can be used as item B (next year), but item B units (next year's vintage) cannot be used as item A (in this year). As a result, the marginal bundle value of one more unit of item A was always at least as high as the marginal bundle value of one more unit of item B. Values for A-B-bundles were given to participants in the form of a 2D value table as displayed in Figure 3.3.

Figure 3.3: Example 2D valuation table

Seat No.	X	Bundle Values									Auction	X
Value (E$)		Quantity Item B										
		0	1	2	3	4	5	6	7	8	9	10
Quantity Item A	0	0	22	44	66	88	107	126	145	164	183	201
	1	27	49	71	93	115	134	153	172	191	210	228
	2	54	76	98	120	142	161	180	199	218	237	255
	3	81	103	125	147	169	188	207	226	245	264	282
	4	108	130	152	174	196	215	234	253	272	291	309
	5	132	154	176	198	220	239	258	277	296	315	333
	6	156	178	200	222	244	263	282	301	320	339	357
	7	180	202	224	246	268	287	306	325	344	363	381
	8	204	226	248	270	292	311	330	349	368	387	405
	9	228	250	272	294	316	335	354	373	392	411	429
	10	250	272	294	316	338	357	376	395	414	433	451
	11	272	294	316	338	360	379	398	417	436	455	473
	12	294	316	338	360	382	401	420	439	458	477	495
	13	316	338	360	382	401	420	439	458	477	495	513
	14	338	360	382	401	420	439	458	477	495	513	531
	15	360	382	401	420	439	458	477	495	513	531	548

Consider a simple example which highlights how those tables are derived.

EXAMPLE

(Note that in this example we use the terms "permit" and "vintage" rather than "unit" and "item A/B", respectively, as in the experiment.)

Assume that a bidder is emitting carbon dioxide and would maximally ask for 2 permits in the first year and 2 permits in the second year. In the first year, his abatement costs would be $15 for the first unit and $20 for the second unit. Therefore, his valuation for permits usable in the first year is $20 for the first permit and $15 for the second permit. We apply a discount factor of 0.8, such that his valuations for permits usable in the second year are $16 for the first permit and $12 for the second permit. (This discount can be interpreted as lower abatement technology costs in the second year, or general discounting of future profits, see below.) We assume unlimited banking, thus permits for vintage 1 can be used in year 1 or in year 2, while permits for vintage 2 can only be used in year 2.

Table 3.4: Example marginal value table

	$margValue vintage 2	Number of vintage 2 permits							
$margValue vintage 1		0		1		2		3	
Number of vintage 1 permits	0		16		12		0		0
		20		20		20		20	
	1		16		12		0		0
		16		15		15		15	
	2		15		12		0		0
		15		12		0		0	
	3		12		0		0		0
		12		0		0		0	

Table 3.4 tabulates the bidder's corresponding marginal values for permits of vintage 1 and vintage 2. For each possible bundle of permits a bidder might already own, the table displays the value of one more vintage 1 permit in the lower left corner of a cell, and the value of one more vintage 2 permit in the upper right corner of the cell. Consider three examples:

- *If the bidder owns 0 permits of vintage 1 and 2 permits of vintage 2 (row 0/ column 2 in Table 3.4), his value for one more permit of vintage 2 is $0, as he already covers his maximum need in year 2, and cannot use the vintage 2 permit to cover his emissions in year 1. One more permit of vintage 1 allows him to cover one more unit of emissions in year 1, therefore his marginal value for one additional unit of vintage 1 permit is $20.*
- *If the bidder owns 1 permit of vintage 1 and 0 permits of vintage 2 (row 1/ column 0 in Table 3.4), his value for one more permit of vintage 2 is $16, as he would be able to cover one unit of permissions in year 2 with this permit. The value of a second permit of vintage 1 is the maximum value at which it can be put into use. If this second vintage 1 permit was used to cover emissions in year 1, then its value would be $15 (the value of a second unit of emission in year 1). However, if the second vintage 1 permit was used in year 2, this would bear a value of $16. The marginal value of one more vintage 1 permit is the maximum of those values, i.e. $16.*
- *Assume the bidder owns 2 permits of vintage 1 and 0 permits of vintage 2 (row 2/ column 0 in Table 3.4). We know that if the bidder owns two permits of vintage 1, then he will use one of these permits to cover a first unit of emissions in year 1 (value $20), and the other permit to cover a first unit of emissions in year 2 (value $16). Now, if the bidder receives one more unit of vintage 1, then he will use it to*

cover a second unit of emissions in year 1 (a value of $15). However, if instead the bidder would purchase one more unit of vintage 2, he would not use it to cover a second unit of emissions in year 2 (a value of $12). Rather he would allocate his permits efficiently, such that the additionally purchased vintage 2 permit is used to replace the vintage 1 permit which previously covered the first unit of emissions in year 2. This way, the freed-up vintage 1 permit can be used where its value is highest: for a second unit of emissions in year 1. Thus, in this case the marginal value of a first vintage 2 permit is equal to the value of a second unit of emissions in year 1, $15.

From Table 3.4 we can easily derive the absolute value for each feasible bundle of vintage 1 and vintage 2 permits. Table 3.5 displays that transformation.

Table 3.5: Absolute values in the example

<table>
<tr><td colspan="2" rowspan="2">Absolute Value of bundle</td><td colspan="5">Number of vintage 2 permits</td></tr>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td rowspan="5">Number of vintage 1 permits</td><td>0</td><td>0</td><td>16</td><td>28</td><td>28</td><td>28</td></tr>
<tr><td>1</td><td>20</td><td>36</td><td>48</td><td>48</td><td>48</td></tr>
<tr><td>2</td><td>36</td><td>51</td><td>63</td><td>63</td><td>63</td></tr>
<tr><td>3</td><td>51</td><td>63</td><td>63</td><td>63</td><td>63</td></tr>
<tr><td>4</td><td>63</td><td>63</td><td>63</td><td>63</td><td>63</td></tr>
</table>

The demand structures for the single vintage treatments were derived from the demand structures in the two vintage treatments. Specifically, the single vintage demand function was calculated by taking the value function of item A assuming an allocation of B units according to the Walrasian equilibrium of the two vintage auction. The values were then normalised such that a “bundle value” for zero item A units is zero (i.e. the value of the bundle “0 units of A and equilibrium units of B” was deducted from each value in the respective column). In other words, the marginal valuations of the item in a single-vintage session were identical to the marginal values of A in the respective two-vintage table, assuming that the bidder acquires the equilibrium quantity of B.

Repetition, Learning, Demand Shocks and Discount Factors

Within each session (bidder group) we conducted 6 auctions. The first two auctions were always simple price clock auctions, with no proxy bidding or other additional features. This allows bidders to learn about the functioning of the auction mechanism and to deal with the complexity (that had turned out to be an issue in first pilot experiments). Moreover, the first two auctions ensured that in all treatments the bidders received the same training and had the same experience at the start of the auctions of their particular treatment. For auctions 3 to 6 the actual auction format according to experimental treatment was introduced. The treatments featured either a sealed bid auction (i.e. a bidding plan submitted in advance, with no opportunity to revise it later), or a proxy clock auction with or without revelation of aggregate demand (i.e. a bidding plan that could be revised anytime for future bidding rounds). For further details on the implementation of the different auction formats see below.

Each of the six auctions in a session employed the same demand structure. However, the “roles” of bidders were rotated between auctions, such that in each auction each bidder received a different individual value function, while the same overall market demand structure was induced. The role rotation shifts were 0, 11, 8, 5, 2, and 13 in auctions 1 to 6, respectively. This series was used in all treatments and sessions.

To prevent bidders from just focusing on the price of the previous auction, and to further explore the robustness of the auction mechanisms, we added exogenous demand shocks and different A-B-discount factors in each auction.

In particular we added constant valuation function shocks of 3, 1, 5, 0, 8, and 6 monetary units in the six auctions, respectively. (This sequence was determined randomly.) In theory, those constant shocks should only shift the resulting auction prices by the same amount. Therefore, in equilibrium (after controlling for the shock) the shocks should not affect market prices, seller revenues, or bidder profits. We employed the same series of shocks in all sessions of our experiments, thereby ensuring comparability of our treatments and sessions.

In each of the six auctions we also varied the valuation function discount factor of the later vintage (item B) with respect to the earlier vintage (item A). The sequence implemented was 0.8, 1, 0.8, 1, 1, 0.8 for auctions 1 to 6, respectively. (This sequence was determined randomly under the condition that 3 auctions employ a factor of 1 and three auctions a factor of 0.8.) A discount factor of 1 makes item B units as valuable as item A units (before accounting for asymmetric substitutability). A discount factor of 0.8 implies that valuations for carbon emissions in the following year are 20% lower than valuations for carbon emissions in this year (even before accounting for permit banking opportunities). This could be due to technology improvements or simple discounting of future profits. In any case, varying the discount factor tests the robustness of the auction against different relative valuations of multiple vintages. The same series of discount factors was used in all sessions of our experiments.

3.1.6 Auction Features Not Tested in the Experiment

Double-Sidedness of Allocation Auctions

While the *White Paper* envisions the opportunity of net suppliers in the permit market to enter the auction as sellers, the discussion at the workshop highlighted that the DCC expects that there will not be many net sellers of permits in the market. The DCC further advised that net sellers will be given the option to add their quantity to the government's supply of permits, but not to submit an individual supply function, such that those sellers would have to accept any price resulting from the auction. This simplifies the auction and gives net suppliers an incentive to trade on secondary markets rather than joining the auction, thereby promoting the development of secondary markets.

As under this proposition the consideration of net sellers has no other effect on the auction than just increasing the quantity offered, there is no need to explore the features of double-sidedness experimentally.

Reserve Price

As the focus of the government is on maximizing allocative efficiency rather than revenue, the discussions in the workshop concluded that a (secret or public) reserve price and a corresponding rule for the case in which the auction is not successful (ends before the reserve price is reached) is not considered to be a crucial feature that needs experimental testing in this study. There was discussion about setting an open reserve price (start price) of $10, equalling the fixed charge per ton of carbon emissions used in 2011/12.

However, reserve prices might nevertheless play a significant role as focal points (if set openly as start price) and in curbing collusion (if set secretly). Moreover, reserve prices close to the secondary market price can be an effective means to reduce incentives for strategic demand reduction. We commented on that in our discussion in Chapter 2.

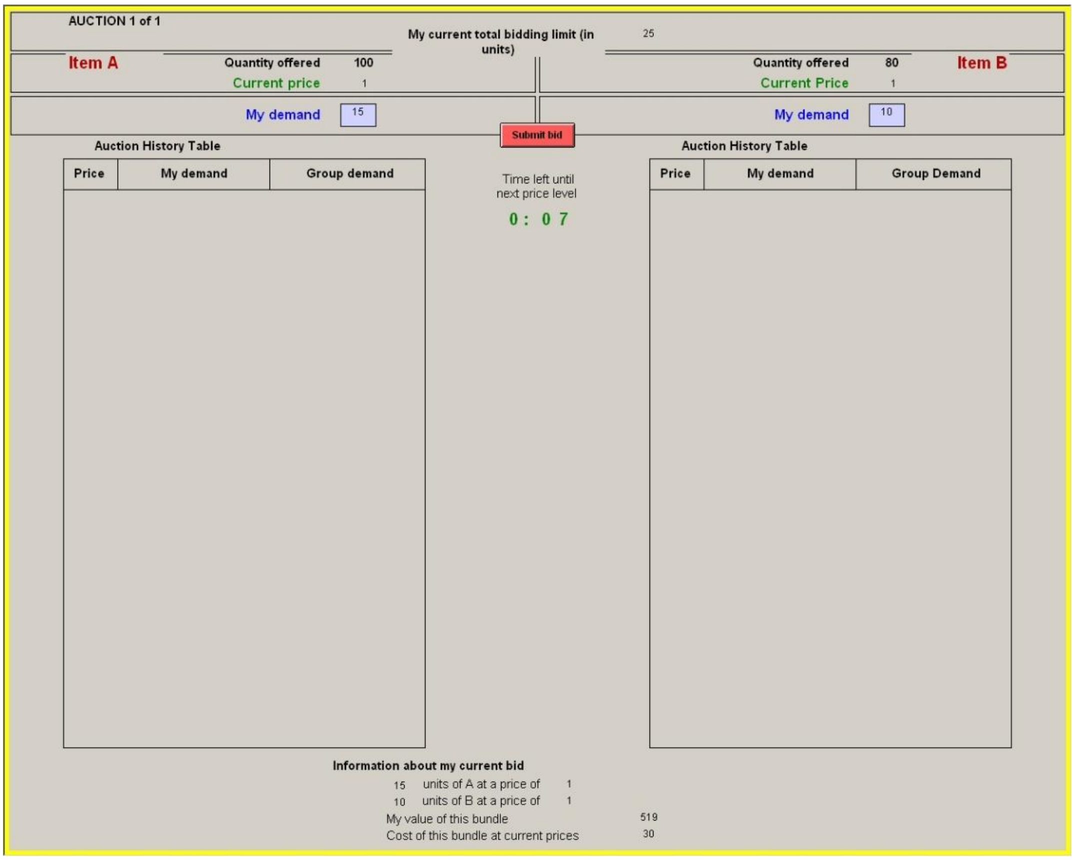
3.2 Experimental Implementation

3.2.1 Experimental Implementation of Auctions

In the following we describe the implementation of the simultaneous two vintage auctions. The single vintage auctions and sequential two vintage auctions were implemented analogously, except that a bidding screen was shown for only one item.

In all treatments, sessions and auctions, we offered 100 units of item A (or the single item) and, in the two-vintage treatments, 80 units of item B. No bidder was allowed to bid for more than 15 units of item A (or the single item) and 10 units of item B. All demand structures used in the experiment induced a per unit valuation of at most E$30 (including demand shocks, E$ = experiment dollars). Thus, we restricted bidding to prices between E$1 and E$30. If at the price of E$1 the aggregate demand was already lower than the supply, the auction would be considered to have failed. (Thus, the E$1 can be thought of as the reserve price.) In none of our experimental auctions did this happen, and in none of our auctions the price went to E$30.

Figure 3.2: Bidding screen in auctions 1 and 2

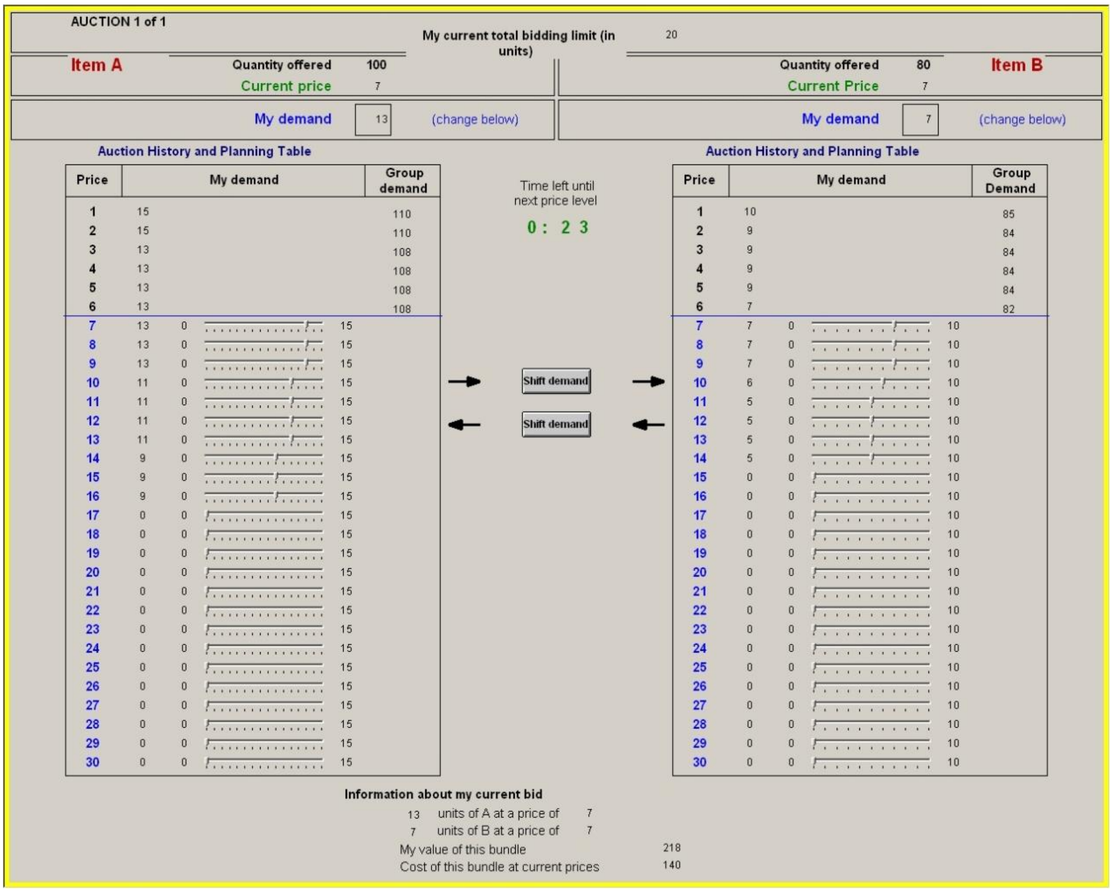


In the first two auctions of each session we implemented a simple clock auction with no proxy bidding. The auction started at a price of E$1 and asked for quantity bids at this price. If the group demand over all bidders at this price was higher than the number of units offered, the price was increased by E$1, and new quantity bids were elicited. This procedure continued until a price clock stopped. Once both clocks stopped at the same time, the auction was over. In these auctions, the activity, stopping, switching, and excess supply rules were implemented as described above. Auction History tables for each item showed the personal bidding history over previous bidding rounds. In the treatments where aggregate demand was revealed, this demand was also displayed in the tables.

After the first two auctions, a video (tailored to each treatment) introduced and explained the submission of proxy bids. In all treatments, the Auction History table of the first two rounds became an "Auction History and Planning table" for the remaining rounds 3 to 6. Sliders at each future clock price allowed bidders to select a bidding plan for the rest of the auction. In the proxy clock auctions, the bidding plan for the current and future prices could be revised at any time during the auction, while sliders for previous prices disappeared.[21]

In the sealed bid format, the complete bidding plan had to be determined before the auction started. Then the auction ran automatically according to the submitted bidding plans, with no possibility of interventions by participants. However, the bid sorting rule was applied in the two vintage sealed bid auctions, automatically correcting the bidding functions such that the price of item B never exceeded the price of item A.

Figure 3.3: Proxy-bidding screen in auctions 3 to 6

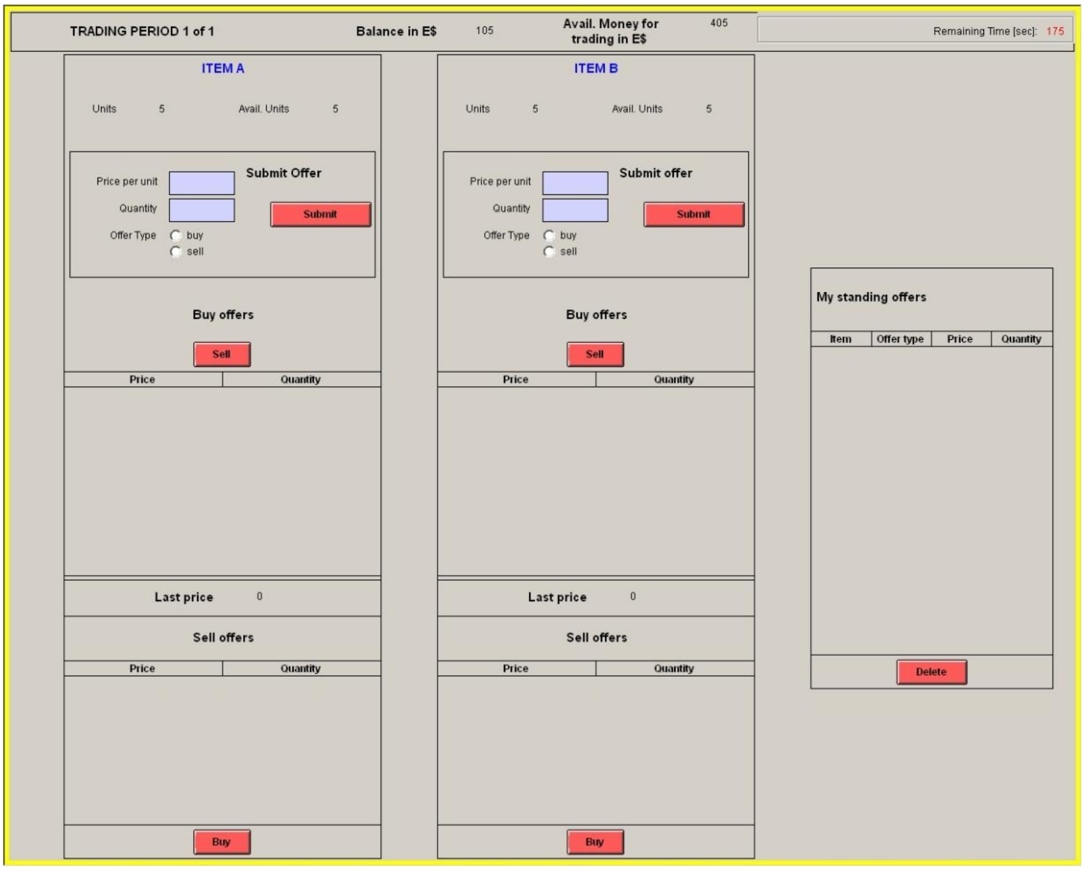


3.2.2 Experimental Implementation of Secondary Market

In treatments T6, T7, and T12, bidders had the opportunity to trade the allocated units on a secondary market after the auction. The market was implemented as a continuous double auction running over 3 minutes. During the market, each trader could post bids and asks at the market or accept any standing offers.

[21] The bidding plan asked for *absolute* quantities demanded at each possible future price. This procedure is theoretically equivalent to the way such auctions have been conducted in practice and previous experiments, which requested a price for each block of permits at the margin. The specific proxy bid design used in the experiment preserves comparability of the auction interface across the different auction formats tested.

Figure 3.4: Secondary market trading screen



3.2.3 Experimental Procedures

The experiments were conducted from January to March 2010 at the University of New South Wales (UNSW) and Karlsruhe University (KU). All 12 main treatments were run at both universities. For each of these treatments, 2 sessions (trader groups) were conducted at UNSW, and 4 sessions at KU. At UNSW, the two trading groups were often run at the same time, as the UNSW laboratory allows for 28 participants at once. Additionally, 3 sessions for the large-group treatment, two with 42 participants each and one with 28 traders, were conducted at UNSW.

Participants were recruited from the ASB Lab subject pool at UNSW and from a respective subject pool at KU. Each participant participated only once in the experiment. Thus, all sessions and conditions involve different subjects. Table 3.6 shows characteristics of the subject pools at UNSW and Karlsruhe.[22] All our experiment participants were students. Students are a convenient and the most commonly used sample in economic experiments: they have low opportunity costs such that they can be sufficiently incentivised without too high experiment costs; they show steep learning curves and are able to understand abstract environments; they are familiar with computers; and they do not exhibit some problematic behaviours observed with non-student subject pools (e.g. professional traders in laboratory experiments often apply only the rules of thumb from their everyday professional activities, rather than adjusting to the lab environment, and therefore perform worse than students).

[22] The subject database at UNSW asks for detailed demographic information, but all information is given voluntarily. The subject database in Karlsruhe only tracks participations but not demographics. Thus, Table 3.6 includes exact numbers for UNSW, but only estimates for Karlsruhe.

Table 3.6: Demographic characteristics of experiment participants

	UNSW	Karlsruhe
N pilots	56	126
N main experiment	448	672
Gender	*Unknown*: 0.9% *Of those known*: Female:51%, Male: 49%	Female: ~25%, Male: ~75%
Began studies / Age	Began studies *Unknown*: 5.3% *Of those known*: <2004: 4.2% 2006: 7.8% 2007: 13.6% 2008: 16.7% 2009: 53.4% 2010: 4.2%	Age 19-21: ~25% 22-25: ~55% 25-30: ~19% >30: ~1%
Fields of studies	*Unknown*: 32.1% *Of those known*: Art & Music: 1.6% Commerce: 25.9% Economics: 17.7% Engineering: 7.5% Env/Geo Sciences: 4.9% Information Systems: 6.9% Law: 6.6% Language and Culture: 2.6% Medical science: 4.3% Psychology: 4.6% Science: 13.4% Social Sciences: 3.9%	Economic engineering, Applied economics, Information systems: >50% Other fields: mechanical engineering, mathematics, chemistry, electric engineering, …
Ethnicity/home country	*Unknown:* 4.0% *Of those known*: Australia/NZ: 16.5% China: 27.4% Other East Asia: 14.8% South Asia: 13.2% South East Asia: 22.0% Europe: 3.5% Other: 2.6%	~95% German

Note: Numbers are exact for UNSW, and estimates for Karlsruhe.

The subjects who participated in the experiment were guaranteed a minimum payoff in the size of the show-up fee of $5 / €5. Subjects who came to the experiment but could not participate (either because the session was already filled or not enough participants for a second trader group showed up) received the show-up fee of $5 / € 5, or a higher fee if longer waiting time was involved.

Instructions were distributed in written form and were also repeated orally, to ensure common knowledge (see the Appendix for a collection of all instructions).

Questions could be asked throughout the instruction phase and the experiment, and were answered privately. After all questions had been answered, participants completed a short computerized comprehension test of up to 16 questions, depending on the treatment (see Appendix). The actual experiment started once the test was completed.

Six auctions were conducted with each trading group. As mentioned before, the first two auctions did not involve proxy bids or sealed bid procedures, but rather a simple clock auction design. This way, participants could familiarise themselves with the procedure of a multi-unit auction without being overwhelmed by a too complex design right from the start. Even more important, this ensured that in all treatments the participants had the same information and experience at the start of the actual treatment auctions.

After two auctions, the auction design switched to the actual treatment design: a sealed bid auction (i.e. a bidding plan for the auction submitted in advance), a proxy-clock auction (i.e. a clock auction with the non-binding opportunity to plan ahead), with revealing aggregate demand or without revealing the aggregate demand. To explain the change in the bid submission procedures, participants were shown a video on the computer screen (with the audio channelled either through headsets (UNSW) or per speaker (KU)). The video lasted between 3 and 5 minutes, depending on treatment. Participants in the sealed bid auction format received the additional instructions also in written form as they had to submit their bid function in advance, without the opportunity to revise. Then, auctions 3 to 6 were run according to the respective treatment.

At the end of the experiment session, one of the 6 auctions was randomly selected for payoff. At UNSW, one participant drew a card out of a hidden and shuffled deck of cards numbered 1-6, at KU the auction was randomly drawn outside of the laboratory and then announced to the participants. Then participants were paid privately in cash and left the laboratory.

During the experiment, E$ (experiment dollars) were used as the currency. For the randomly selected auction, participants were paid their profits/losses from the auction (and secondary market), plus a lump-sum of E$150 (E$200 in the secondary market treatments) to cover potential losses. The E$ were converted at a publicly known exchange rate of AUS$0.15 / E$ at UNSW and Euro 0.10 / E$ in Karlsruhe (AUS$ 0.30 / E$ and Euro 0.20 / E$, respectively, in the single vintage treatments). On average, participants earned AUS$ 31.77 at UNSW and Euro 22.31 at KU, including show-up fees.

3.3 Main Hypotheses

Based on the discussion above, concerning auction formats and market complexity, the following main hypotheses were formulated for the experiments:

1. Single vintage: lower prices with open clock. In the single vintage case and with two vintages auctioned sequentially, clock auctions with aggregate demand revelation lead to lower prices (higher bid shading) than clock auctions without aggregate demand revelation or sealed bid auctions, which are similar.
2. Multiple vintages: lower prices with clock. If two vintages are auctioned simultaneously, a clock auction with aggregate demand revelation leads to lower prices than a clock auction without aggregate demand revelation which in turn leads to lower prices than a sealed bid auction.
3. Better price discovery with open clock. Prices are closer to Walrasian equilibrium and less volatile when using a clock auction with aggregate demand revelation than when using a sealed bid auction.
4. Higher efficiency with simultaneous auctions. If two vintages are to be auctioned off, then a simultaneous auction yields a more efficient allocation than a sequential auction.
5. Secondary market increases efficiency. If secondary markets exist, the allocation after trading is more efficient than the allocation before trading on the secondary market.

4. Results of the Experiment

4.1 Introduction

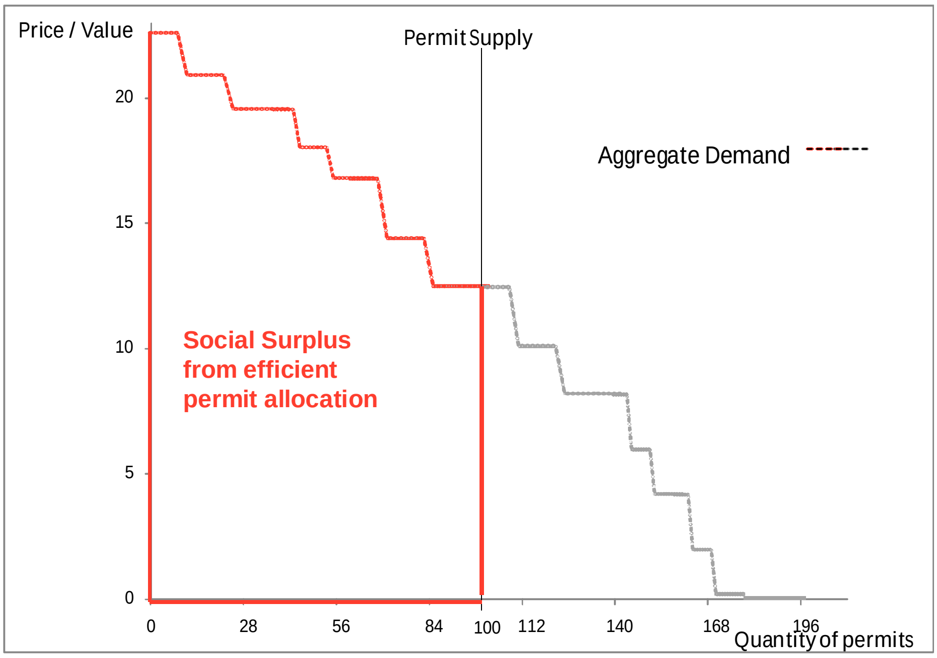
4.1.1 Performance Measures

In evaluating the performance of auction formats in different market environments, we follow the market design literature and use the "Walrasian equilibrium" as a benchmark.

In the carbon permit trading scheme, companies need to surrender permits according to their emissions, otherwise they will be penalised. Before the initial allocation occurs, the government holds all permits, but has no direct value for those permits. At the same time, emitting companies need permits in order to produce, but do not hold any, yet.

By allocating permits to emitting companies (through auctions or any other procedure), a social surplus is generated, as ownership of permits is transferred from the government, which has no value for them, to emitters who value them at their abatement costs. This social surplus is maximized if permits are allocated to those emitters who have the highest abatement costs (i.e. the highest valuations for permits).

Figure 4.1: Efficient allocation of permits

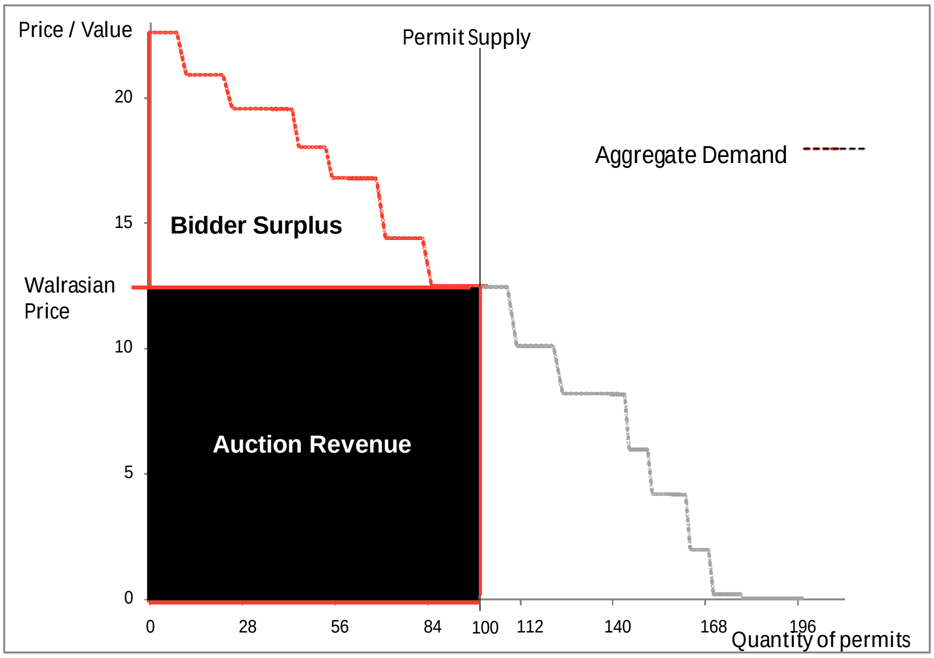


If the government possessed complete information about the abatement costs of all emitting companies, it could allocate permits in an efficient way. This would ensure that the government was reaching the goal of achieving the carbon emission reduction at the lowest economic costs, as those firms with the lowest abatement cost will be forced to abate.

Alternatively, if it possesses such complete information, the government could reach the same allocation by posting a price for permits such that those who received permits in the efficient allocation described above would buy and those who did not receive permits in the above allocation would not buy.

This competitive price which yields an efficient allocation is called the "Walrasian price", and the efficient allocation at this prices is called the "Walrasian equilibrium". This notion extends to multiple permit types (vintages) sold at multiple prices. The Walrasian prices and the respective allocation should be observed after trading in perfectly competitive markets.

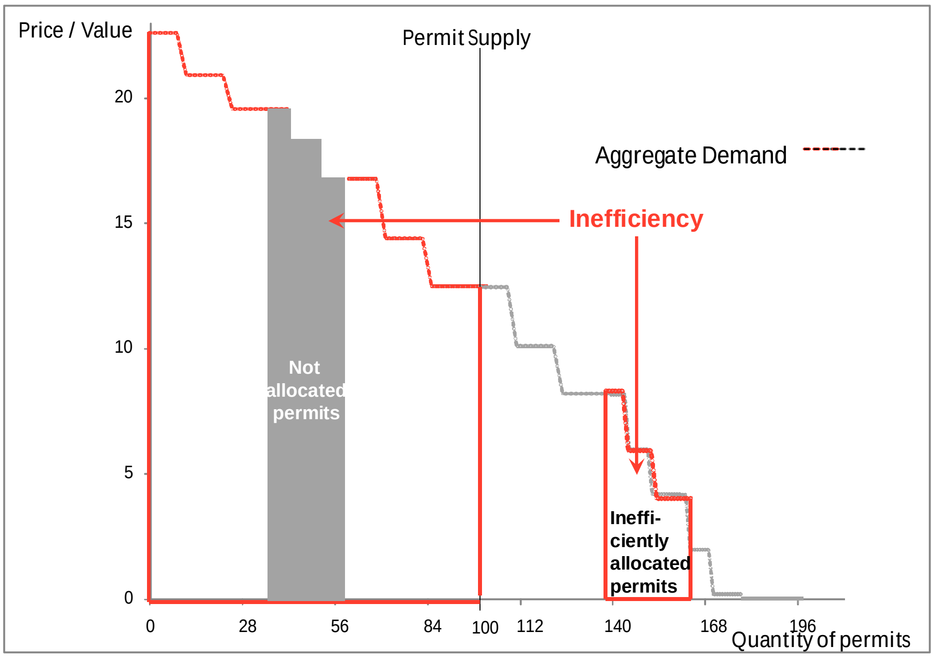
Figure 4.2: Walrasian equilibrium, auction revenue and bidder surplus



If permits are allocated for free, the social surplus is fully transferred to emitters. If a price offer as above is used, the surplus is divided into the government's share (as emitters have to pay for the permits they receive) and the emitters' share (as many emitters only have to pay a price lower than their actual value for the permits, and thereby still realize a surplus).

If no complete information about emitters' valuations is available, a mechanism needs to be used to allocate the permits. However, a 100 per cent efficient (initial) allocation is difficult to achieve by basically any allocation method (e.g. free allocation based on benchmarks or auctions). If bidders do not bid according to their true values, auctions may not yield a perfectly efficient allocation among the bidders and prices will differ from Walrasian prices. The same holds for the corresponding seller revenues and bidder surpluses. As Figure 4.3 demonstrates, inefficiencies in the allocation occur if permits are allocated to bidders with lower values rather than other bidders who have higher values for permits (see grey area).

Figure 4.3: Potential inefficiencies in permit allocation



Thus, we will consider the following performance measures to evaluate our experimental results over different treatments:

- Allocative efficiency: One of the primary goals of the CPRS auctions is to assign the units auctioned off to the bidders with the highest valuations for those units. The social surplus of an allocation is a measure of how efficient the allocation is in terms of value realisation. Thus, we define the relative efficiency of an auction as the fraction of the realised social surplus over the maximal social surplus (the surplus reached in a Walrasian equilibrium with efficient allocation of units, Figure 4.1).

- Dynamic efficiency: Another goal of the CPRS auction is to create consistent price signals in order to incentivise emission reductions in those areas of the economy where this can be accomplished most cheaply. Too high prices might induce inefficient abatement; too low prices might yield a delay in areas where abatement would be efficient. We measure the relative prices generated by the auction relative to the competitive price in the Walrasian equilibrium (see Figure 4.2).

- Seller revenues and bidder surplus: The social surplus can be divided into the seller surplus (seller revenues from the auction) and the buyer surplus (bidder profits). The relation between seller revenues and bidder profits, i.e. how the social surplus is distributed, is determined by the final prices of the auction. Even though it is not the primary goal of the government to maximise auction revenues, those measures also give indications about potential demand reduction and collusion among bidders. Thus, we include seller revenues and bidder surpluses relative to the Walrasian benchmark (see Figure 4.2) as measures of auction performance.

- Bidding activity: We also inspect load profiles of bidding activity over time to evaluate the performance and participants' acceptance of the proxy bidding mechanism.

4.1.2 Statistical Analysis

In this chapter we use the following abbreviations to refer to our experimental parameters:

- Auction type:
  - SB: Sealed Bid auction
  - CDR: Clock auction with aggregate demand revealed (open clock)
  - CDNR: Clock auction with aggregate demand not revealed (closed clock)
- Market environment:
  - 1Vint: one vintage auctioned
  - 2VintSeq: two vintages auctioned sequentially
  - 2VintSim: two vintages auctioned simultaneously
  - 2VintSimSM: two vintages auctioned simultaneously, with subsequent secondary market
  - 2VintSeq Large Groups: same as 2VintSeq with CDR, only that those sessions were conducted with large bidder groups (42 resp. 28 traders)

In a first step of the analysis, we adjusted the data by taking out the demand shocks as explained in Chapter 3. Additionally we restrict the dataset to auctions 3 to 6 in each session, as the first two auctions were not fully configured with all features of the treatment being tested and were intended to allow for learning.

Besides inspections of our measures of interest we also apply statistical analysis. In particular we employ two popular methods.

Nonparametric statistical tests. Experiment sessions (=trader groups) are our unit of independent statistical observation. Thus, we average the measures of interest for each session, and then use a non-parametric test to compare the values for the six sessions of one treatment to the values of the six sessions of another treatment. Those sessions are compared pair-wise (as each session represented one demand schedule, which was employed once in each treatment). The statistical tests compare the distributions of the values for one treatment and the values for the other treatment, and detect whether there is a shift in one or the other direction between those distributions. The test we employ throughout is the two-tailed “Wilcoxon Matched Pairs Signed Ranks” test. It is a conservative test, detecting differences only if they are stark, but does not require many assumptions about the shapes of the two distributions to be compared.

Ordinary Least Square (OLS) Regression Analysis. Regressions start with a model of how individual independent parameters (our treatment parameters) may have influenced the dependent variable (the performance measure of interest). In running the regressions, we fit the parameters of this model (coefficients) to the data, such that with the estimated coefficients (weights for the independents), the model’s predictions come as close as possible to the actually observed data. As a measure of fit, OLS regressions use the squared deviations between predicted and actual data points. The estimated regression coefficients can be interpreted as the effect of changing only one auction design feature, while holding all other auction design features constant.

As the one-vintage and two vintage treatments are not directly comparable, the first regressions reported below only include the data from two-vintage auctions. Separate regressions on one-vintage auctions are presented and discussed at the end of this chapter (cf. Table 4.9).

In the regressions we use the following independent (explanatory) variables.

- isClock measures the effect of having a clock auction (with unrevealed aggregate demand) rather than a sealed bid auction.
- isClock:isClockOpen measures the effect of additionally revealing the aggregate demand in the clock auction.
- isSeq measures the additional effect of auctioning off the two vintages sequentially rather than simultaneously.
- hasSM measures the additional effect if there is a secondary market after the simultaneous auction.

Thus, treatment effects have been partitioned into marginal auction/market feature effects. The baseline case is the sealed bid format with both vintages auctioned simultaneously. All effects are the marginal effects in comparison to this baseline.

As further controls we include:

- isLargeGroup equals 1 for treatment 13 in which large bidder groups were used, and 0 otherwise
- DemandShock equals the demand shock in the individual auction. If bidders behave as theory predicts, then this variable should not yield any significant effect, since in the data the demand shocks are already neutralised.
- RelVintValueScheme is a dummy variable, equalling 1 for auctions with a value relation of B/A of 1, and 0 for auctions with a B/A relation of 0.8. Thus, the coefficient of this independent variable will pick up the effect of the relative value of item B with respect to item A.
- Session Fixed Effects ("Session FE" in tables below) are allowing specific effects for each of our demand schedules (= sessions 1 to 6 in each treatment). By including these effects in the regression we aim to neutralise the effect that a specific demand schedule might have on the outcome variable, such that we are able to measure the other effects as general effects valid for any demand schedule.
- Auction Fixed Effects ("Auction FE" in tables below) introduce similar sorts of specific effects for each of the four included auctions from each session. When including auction fixed effects, the independents *DemandShock* and *RelVintValueScheme* become obsolete, as they are defined per auction. Thus, we run each regression model once with auction fixed effects and once without. A comparison shows us to what extent *DemandShock* and *RelVintValueScheme* are able to account for the differences between auctions, or whether there are any additional effects not explained by those two independent variables. As our results below show, including auction fixed effects generally does not increase the explanatory power of the regression model. Thus, *DemandShock* and *RelVintValueScheme* seem to be sufficient statistics of an auction within a session.

Tables 4.10 and 4.11, located at the end of this chapter, present average efficiencies, auction revenues, bidder surpluses, relative prices and price variances for all experimental sessions of all treatments.

4.2 Allocative Efficiency

Table 4.1 gives an overview of relative auction efficiency (realised social surplus compared to the Walrasian social surplus) in all our experimental conditions. Table 4.2 shows the results of regressions of relative efficiency on treatment parameters and controls. Models 1 and 2 in this table analyse allocation efficiency after the auction but before a potential secondary market. Models 3 and 4 analyse allocation efficiency including potential re-allocations in a secondary market. (Thus, only for our secondary market treatments the underlying data is different in Models 3 and 4 compared to

Models 1 and 2.) As described above, the first model of each regression model pair includes the independents *DemandShock* and *RelVintValueScheme* as controls, while the respective second model replaces those controls with auction fixed effects.

In general, efficiencies in all our two-vintage treatments are very close to each other. We find no consistent significant effect of the auction design (sealed bid vs. closed clock vs. open clock) on the efficiency of the allocation, neither in the non-parametric tests nor in the regression. The only outlier in this regard is the statistically significant difference between open clock and sealed bid auction in the two-vintage simultaneous auction case. This, however, has to be interpreted very carefully, as the large number of statistical tests we run increases the likelihood of spurious significance results.

The regressions in Table 4.2 consistently detect a significant effect of about 1.2% efficiency gains when auctioning sequentially rather than simultaneously. This effect is, however, not detected in the more conservative non-parametric tests.

Table 4.1: Treatment averages and non-parametric tests of auction efficiency

Relative Efficiency of Auctions			
	SB	CDNR	CDR
1Vint	95.3%	93.6%	96.0%
2VintSeq	89.5%	88.3%	88.8%
2VintSim	85.9%	88.4%	88.7%
2VintSimSM (before Secondary Market)	86.9%	87.5%	88.0%
2VintSimSM (after Secondary Market)	87.1%	87.7%	87.1%
2VintSeq Large Groups			94.1%

Wilcoxon Tests results			
	SB vs. CDNR	CDR vs. CDNR	SB vs. CDR.
1Vint	n.s.	n.s.	n.s.
2VintSeq	n.s.	n.s.	n.s.
2VintSim	n.s.	n.s.	**
2VintSimSM (before Secondary Market)	n.s.	n.s.	n.s.
2VintSimSM (after Secondary Market)	n.s.	n.s.	n.s.
	SB	CDNR	CDR
2VintSeq vs. 2VintSim	n.s.	n.s.	n.s.

Notes: All tests are two-tailed. *, **, *** indicate statistical significance of differences at the 10%, 5%, 1% level.

We find no efficiency effects of having a secondary market. We detect neither an effect of the existence of a secondary market on the efficiency of the auction itself (before secondary market trading), nor do we observe an increase in efficiency through trading in the secondary market.

The auctions in the large group sessions (employing a sequential open clock design) turned out to be particular efficient. However, the regressions do not pick up this effect, and due to only three observations non-parametric tests are not feasible for this treatment cell.

Comparing between regression models (Model 1 vs. 2 and Model 3 vs. 4 in Table 4.2, respectively), there is no increase in r-squared when we include auction fixed effects rather than the auction-specific parameters *DemandShock* and *RelVintValueScheme*.

This result also holds for all other regressions presented in this chapter. It indicates that those two variables have sufficient explanatory power for differences between auctions. In other words: the differences between the auctions in our sessions (the demand shock and the relative value of item B with respect to item A) seem not to have any other unobserved or uncontrolled effects on behaviour than the ones detected to be significant and reported below.

The efficiency measures reported in Table 4.1 also demonstrate that one-vintage and two-vintage auctions are different by design, the particularly high efficiency with only one vintage is due to the construction of the experiment.[23]

Table 4.2: OLS regressions of relative auction efficiency on treatment parameters

	Efficiency before SM	Efficiency before SM	Efficiency after SM	Efficiency after SM
Dependent				
Model	1	2	3	4
Intercept	0.759***	0.755***	0.764***	0.761***
	(0.008)	(0.008)	(0.008)	(0.008)
Auction rule				
isClock	0.007	0.007	0.007	0.007
	(0.005)	(0.005)	(0.005)	(0.005)
isClock:isClockOpen	0.004	0.004	0.001	0.001
	(0.005)	(0.005)	(0.005)	(0.005)
Market environment				
isSeq	0.012**	0.012**	0.012**	0.012**
	(0.005)	(0.005)	(0.005)	(0.005)
hasSM	-0.002	-0.002	-0.004	-0.004
	(0.005)	(0.005)	(0.005)	(0.005)
Controls				
isLargeGroup	-0.014	-0.013	-0.010	-0.010
	(0.012)	(0.012)	(0.012)	(0.012)
DemandShock	-0.001		-0.001	
	(0.001)		(0.001)	
RelVintValueScheme	-0.001		-0.003	
	(0.004)		(0.005)	
Session FE	Y	Y	Y	Y
Auction FE	N	N	N	N
N	225	225	225	225
Adj. R-square	0.8319	0.8315	0.8125	0.8119

Notes: Only two-vintage auctions are included in the regression analysis. Standard errors of estimates are given in brackets. *, **, *** indicate statistical significance of the parameter at the 10%, 5%, 1% level, respectively.

[23] The demand function for single unit auctions was calculated by taking the value function of item A assuming an allocation of B units according to the Walrasian equilibrium of the two vintage auction.

4.3 Dynamic Efficiency: Auction Prices

Table 4.3 reports average relative prices (with respect to the Walrasian benchmark) in both single-vintage treatments (single price) and in the two-vintage treatments (prices for item A and item B), and includes test statistics from Wilcoxon tests comparing these averages. In Table 4.4 we display results of regressions of prices on treatment parameters, based on the two-vintage auction data. Models 5 and 6 are regressions of the relative price of item A, with controls and auction fixed effects, respectively. Models 7 and 8 present the respective regressions of the relative price of item B. Finally, Table 4.5 reports, per treatment, the average variance of prices within experiment sessions, as well as statistical tests based on this data.

Consistent with the results for auction efficiency, we do not find trends of prices of item A with respect to the auction format. Although in 5 out of 6 comparisons in two-vintage auctions clock prices seem to be somewhat higher than sealed bid prices, none of the statistical comparison for the price of item A detects any significant differences. For item B, some significant but inconsistent results are obtained: under simultaneous auctioning, a closed clock design yields a higher price of B than with sealed bid or an open clock, while under sequential auctioning the price of item B in the sealed bid format is higher than with a closed clock.

Table 4.3: Treatment averages and non-parametric tests of prices relative to Walrasian price, for items A and B

Relative prices A / B			
	SB	CDNR	CDR
1Vint	0.893	0.879	0.874
2VintSeq	0.985 / 0.846	0.994 / 0.743	0.981 / 0.807
2VintSim	0.860 / 0.715	0.900 / 0.828	0.879 / 0.763
2VintSimSM	0.824 / 0.680	0.854 / 0.737	0.853 / 0.739
2VintSeq Large Groups			1.015 / 0.796

Wilcoxon Tests results			
	SB vs. CDNR	CDR vs. CDNR	SB vs. CDR.
1Vint			
2VintSeq	n.s. / *	n.s. / n.s.	n.s. / n.s.
2VintSim	n.s. / **	n.s. / *	n.s. / n.s.
2VintSimSM	n.s. / n.s.	n.s. / n.s.	n.s. / n.s.
	SB	CDNR	CDR
2VintSeq vs. 2VintSim	* / *	* / n.s.	** / n.s.

Notes: All tests are two-tailed. *, **, *** indicate statistical significance of differences at the 10%, 5%, 1% level, respectively.

However, in non-parametric tests we can observe a (weakly) significant positive effect on the price of the item auctioned first (item A) when two items are auctioned sequentially rather than simultaneously. This result is robust across auction formats, and is additionally confirmed in the regressions reported in Table 4.4. The estimated coefficient for the binary dummy parameter *isSeq* indicates that the price of item A is about 10% higher compared to the Walrasian benchmark if item A is auctioned first rather than simultaneously with item B. No consistent effects of sequence are observed for the relative price of item B.

There is a positive effect of auctioning sequentially under the sealed bid format, but under both other formats no significance is detected, and the relation is even reversed in the closed clock auction design.

Unexpectedly, the regression models indicate that auction prices for both item A and B are slightly lower when a secondary market will be run after the auction. Apparently, bidders are more cautious in bidding when a trading opportunity exists after the allocation auction.

Also, our controls in the regression turn out to matter for relative prices. In particular, the higher the demand shock of an auction in a session, the lower are the relative prices for items A and B. And if the independent *RelVintValueScheme* equals 1 (i.e. if the A/B-factor is 1 rather than 0.8 such that item B is worth more relatively), then the relative price of B is lower. Theoretically, a shock on the value, like a positive demand shock or a relative value shock, should just shift the price upwards by the same absolute amount, and after deducting the shock from the resulting prices (as we did in cleaning our data and calculating relative prices), no effect should remain. The described effect implies that rather than increasing their bids by the same absolute amount as item values are increased, bidders discount the increase in their bids.

Table 4.4: OLS regressions of relative prices (prices relative to Walrasian price) for item A and item B on treatment parameters

Dependent	RelPriceA	RelPriceA	RelPriceB	RelPriceB
Model	5	6	7	8
Intercept	0.940***	0.898***	0.868***	0.827***
	(0.026)	(0.024)	(0.032)	(0.030)
Auction rule				
isClock	0.026	0.026	0.023	0.023
	(0.017)	(0.017)	(0.020)	(0.020)
isClock:isClockOpen	-0.012	-0.012	0.000	0.000
	(0.016)	(0.016)	(0.020)	(0.020)
Market environment				
isSeq	0.107***	0.107***	0.030	0.030
	(0.017)	(0.017)	(0.020)	(0.020)
hasSM	-0.036**	-0.036**	-0.050**	-0.050**
	(0.017)	(0.017)	(0.020)	(0.020)
Controls				
isLargeGroup	0.038	0.042	-0.002	0.005
	(0.037)	(0.037)	(0.046)	(0.046)
DemandShock	-0.009***		-0.010***	
	(0.002)		(0.003)	
RelVintValueScheme	0.004		-0.037**	
	(0.014)		(0.017)	
Session FE	Y	Y	Y	Y
Auction FE	N	Y	N	Y
N	225	225	225	225
Adj. R-square	0.3397	0.3421	0.1134	0.1219

Notes: Only two-vintage auctions are included in the regression analysis. Standard errors of estimates are given in brackets. *, **, *** indicate statistical significance of the parameter at the 10%, 5%, 1% level, respectively.

A study of price variance within experiment sessions in Table 4.5 indicates that price volatility is lower in an open clock auction than in a sealed bid auction, significantly so for prices of item A in single-vintage and simultaneous two-vintage auctions. As expected, this effect is not observed for closed clock auctions. The lowest overall variances are found for the sequential auction of two vintages in the open clock format, in particular if large bidder groups are present.

Table 4.5: Average Variances of relative prices (prices relative to Walrasian price)

Variances of relative prices A / B	SB	CDNR	CDR
1Vint	0.0069	0.0259	0.0017
2VintSeq	0.0037 / 0.0066	0.0070 / 0.0078	0.0031 / 0.0048
2VintSim	0.0099 / 0.0071	0.0057 / 0.0055	0.0046 / 0.0096
2VintSimSM	0.0129 / 0.0201	0.0076 / 0.0089	0.0032 / 0.0100
2VintSeq Large Groups			0.0014 / 0.0029

Wilcoxon Tests results	SB vs. CDNR	CDR vs. CDNR	SB vs. CDR.
1Vint	n.s.	n.s.	*
2VintSeq	n.s. / n.s.	n.s. / n.s.	n.s. / n.s.
2VintSim	n.s. / n.s.	n.s. / *	* / n.s.
2VintSimSM	n.s. / *	n.s. / n.s.	** / n.s.
	SB	**CDNR**	**CDR**
2VintSeq vs. 2VintSim	* / n.s.	n.s. / n.s.	n.s. / n.s.

Notes: All tests are two-tailed. *, **, *** indicate statistical significance of differences at the 10%, 5%, 1% level, respectively.

4.4 Auction Revenues and Bidder Surplus

Table 4.6 displays treatment averages and statistical tests of auction revenues (seller profits) in our experiment.

Table 4.6: Treatment averages and non-parametric tests of auction revenues relative to revenues in Walrasian equilibrium

Relative auction revenues	SB	CDNR	CDR
1Vint	89.3%	87.9%	87.4%
2VintSeq	92.6%	88.7%	90.7%
2VintSim	79.8%	87.0%	82.9%
2VintSimSM	76.2%	80.4%	80.2%
2VintSeq Large Groups			92.0%

Wilcoxon Tests results			
	SB vs. CDNR	CDR vs. CDNR	SB vs. CDR.
1Vint	n.s.	n.s.	n.s.
2VintSeq	n.s.	n.s.	n.s.
2VintSim	n.s.	n.s.	n.s.
2VintSimSM	n.s.	n.s.	n.s.
	SB	CDNR	CDR
2VintSeq vs. 2VintSim	**	n.s.	**

Notes: All tests are two-tailed. *, **, *** indicate statistical significance of differences at the 10%, 5%, 1% level, respectively.

Table 4.7 shows the corresponding regression results in regression models 9 and 10. Table 4.8 reports averages and tests for bidder profits, with results from regressions also reported in Table 4.7, Models 11 and 12. Both performance measures are expressed relative to the revenues and bidder profits in the Walrasian equilibrium, respectively.

As Table 4.6 shows, the auctions in our experiment yield between 76.2% and 92.6% of the revenues which would be predicted by Walrasian equilibrium, i.e. by efficient prices reflecting marginal costs. We do not observe any significant difference in auction revenues between auction formats (sealed bid vs. closed clock vs. open clock). However, consistent with the observed effects on item A prices, we detect higher revenues when auctioning sequentially rather than simultaneously. This difference is significant for sealed bid and open clock formats, but not for the closed clock auction design.

Table 4.7: OLS regressions of auction revenues and bidder surplus (relative to Walrasian revenues and surpluses) on treatment parameters

Dependent	Seller Revenue	Seller Revenue	Bidder Surplus	Bidder Surplus
Model	9	10	11	12
Intercept	0.912***	0.870***	0.072	0.286***
	(0.025)	(0.024)	(0.118)	(0.111)
Auction rule				
isClock	0.025	0.025	-0.055	-0.055
	(0.016)	(0.016)	(0.076)	(0.076)
isClock:isClockOpen	-0.007	-0.007	0.052	0.052
	(0.016)	(0.016)	(0.076)	(0.076)
Market environment				
isSeq	0.074***	0.074***	-0.290***	-0.290***
	(0.016)	(0.016)	(0.076)	(0.076)
hasSM	-0.043***	-0.043***	0.177**	0.177***
	(0.016)	(0.016)	(0.076)	(0.076)
Controls				
isLargeGroup	0.020	0.025	-0.054	-0.075
	(0.036)	(0.036)	(0.170)	(0.170)
DemandShock	-0.010***		0.047***	
	(0.002)		(0.011)	
RelVintValueScheme	-0.019		0.133**	
	(0.013)		(0.063)	
Session FE	Y	Y	Y	Y
Auction FE	N	Y	N	Y
N	225	225	225	225
Adj. R-square	0.2629	0.2695	0.5475	0.5501

Notes: Only two-vintage auctions are included in the regression analysis. Standard errors of estimates are given in brackets. *, **, *** indicate statistical significance of the parameter at the 10%, 5%, 1% level, respectively.

The regressions of auction revenues in Table 4.7 confirm the observation of no effect of auction format and a positive effect of auctioning sequentially on auction revenues. The other effects mirror the results obtained for relative prices. This is not surprising, as higher auction prices *ceteris paribus* increase seller revenues and decrease bidders' surplus. As for prices, the existence of a post-auction secondary market has a slight negative effect, and auction revenues do not increase by the full amount that would be predicted by a positive demand shock.

In Table 4.8 we observe quite some variance in bidder surpluses among treatments. However, we do not observe clear and significant trends in bidder profits between auction formats. The only outlier is a weakly significant positive effect on bidder profits when using a clock auction rather than a sealed bid format. Bidder profits seem to be substantially lower when auctioning sequentially rather than simultaneously. While this is consistent with the discussed effects on prices and auction revenues, and turns out to be significant in the regressions reported in Table 4.7, in the non-parametric tests the effect is statistically detectable only for the open clock auction. In the regressions in Table 4.7, bidder profits show exactly the opposite behaviour: they are lower when auctions are sequential rather than simultaneous, and increase in demand shocks which should be neutral to bidder profits according to theory.

The only dependent variable having the same effect on auction revenue and bidder profits (but only significantly so on bidder profits) is the *RelVintValueScheme* dummy (i.e. the A/B factor): making B worth more benefits both the seller and the bidders in terms of auction revenues and bidder surplus.

Table 4.8: Treatment averages and non-parametric tests of bidder surplus relative to Walrasian benchmark

Relative bidder surplus	SB	CDNR	CDR
1Vint	121.9%	118.3%	134.6%
2VintSeq	75.9%	88.7%	84.7%
2VintSim	118.6%	99.1%	118.5%
2VintSimSM (before Secondary Market)	136.2%	126.4%	126.6%
2VintSimSM (after Secondary Market)	135.9%	127.4%	121.7%
			117.8%

Wilcoxon Tests results	SB vs. CDNR	CDR vs. CDNR	SB vs. CDR.
1Vint	n.s.	n.s.	*
2VintSeq	n.s.	n.s.	n.s.
2VintSim	n.s.	n.s.	n.s.
2VintSimSM (before Secondary Market)	n.s.	n.s.	n.s.
2VintSimSM (after Secondary Market)	n.s.	n.s.	n.s.

	SB	CDNR	CDR
2VintSeq vs. 2VintSim	n.s.	n.s.	**

Notes: All tests are two-tailed. *, **, *** indicate statistical significance of differences at the 10%, 5%, 1% level, respectively.

4.4.1 Performance of Single-Vintage Auctions

As the complexity and value structure of single vintage environments is substantially different by design in our experiments, all regressions discussed above only contained the data from two-vintage treatments. In Table 4.9 we report separate regressions based on the single-vintage data, for auction efficiency (as realized social surplus relative to the Walrasian social surplus, regression models 1 and 2), relative auction price (final price relative to Walrasian price, regression models 3 and 4), and relative bidder surplus (relative to bidder surplus in Walrasian equilibrium, regression models 5 and 6). As before, the first model in each of those pairs includes controls for demand shock and A/B-factor, while the second model replaces those controls with auction fixed effects, respectively. Note that we do not report a regression of seller surplus, as in the single-vintage auction the seller surplus is exactly equal to 100 units times the auction price, such that the seller surplus regression yields exactly the same results as the auction price regression.

The only noteworthy effect (other than what was reported above in the discussions of averages and non-parametric tests) is that in Models 1 and 2 in Table 4.9 we observe a small negative effect of having a closed clock auction on efficiency, which is however mitigated once the clock auction is open. However, the combined effect (i.e. the full effect of having an open clock auction compared to a sealed bid auction in the single vintage case) is not significantly different from zero.

Table 4.9: OLS regressions of relative efficiency, price, and bidder surplus in single vintage treatments on treatment parameters

Dependent Model	Efficiency 1	Efficiency 2	RelPrice 3	RelPrice 4	Bidder Surplus 7	Bidder Surplus 8
Intercept	0.941 ***	0.942 ***	0.843 ***	0.837 ***	1.217 ***	1.314 ***
	(0.014)	(0.013)	(0.050)	(0.045)	(0.245)	(0.227)
Auction rule						
isClock	-0.017 *	-0.017 *	-0.014	-0.014	-0.036	-0.036
	(0.010)	(0.010)	(0.035)	(0.034)	(0.168)	(0.168)
isClock:isOpen	0.024 **	0.024 **	-0.005	-0.005	0.163	0.163
	(0.010)	(0.010)	(0.035)	(0.034)	(0.168)	(0.168)
Controls						
DemandShock	-0.001		-0.008		0.036	
	(0.001)		(0.005)		(0.024)	
RelVintValScheme	-0.008		-0.006		0.104	
	(0.008)		(0.029)		(0.142)	
Session FE	Y	Y	Y	Y	Y	Y
Auction FE	N	Y	N	Y	N	Y
N	72	72	72	72	72	72
Adj. R-square	0.1591	0.1838	0.08414	0.1378	0.03183	0.04028

Notes: Only single-vintage auctions are included in the regression analysis. Standard errors of estimates are given in brackets. *, **, *** indicate statistical significance of the parameter at the 10%, 5%, 1% level, respectively.

4.5 Bidding Activity (Load Profiles) and Use of Proxy Option in Clock Auctions

We start analysing bidding activity by looking at the number of changes bidders make to their current bid (at the current price) in the course of a clock auction. In the pure clock auctions with no proxy bidding, those changes reflect nothing other than the reduction of bidding quantity while the prices rise. Therefore, bidding activity in the simple clock (pooled over both information conditions) serves as our baseline case.

With proxy bidding bidders have the opportunity to plan ahead. By submitting a bidding plan they do not have to change their bid with every new price. Thus, we expect that bidding activity for current bids is lower with proxy bidding than without proxy bidding. Also the revelation of aggregate demand might have an effect on bidding activity, as it reveals new and more information than if the aggregate demand is not revealed. In particular the information that the end of the auction is close (as the excess demand is small) might have a stimulating effect on bidding activity.

Figures 4.4 and 4.5 show bidding activity load profiles separately for item A (or the single item) and item B, for both proxy clock auctions with demand revelation and without demand revelation.

In Figure 4.4 we depict changes of bids at current auction prices over the course of the auction. In all treatments we observe increasing activity over time: the higher the prices, the more often do bidders change (reduce) their quantities. As expected, the bidding activity in proxy treatments is indeed strictly lower than without the proxy option. The activity seems to be lowest in the sequential auctions, for both items A and B, and is even lower than in the single vintage case. With no revelation of aggregate demand the most activity at the end of an auction seems to be on the B item, when the A item price clock has just stopped. Contrarily, when aggregate demand is continuously revealed, bidding activity peaks at the end of the auction for both A and B, probably reflecting that both price clocks close simultaneously.

Figure 4.5 shows the changes of the proxy bidding *function*, i.e. includes not only changes of quantities at current prices (as Figure 4.4), but also changes of the plan as a whole, including quantity bids at future prices. We cannot observe any difference between activity without proxy-bidding and with proxy-bidding in our treatments with single vintages and two vintages auctioned simultaneously. In other words, while proxy-bidding in those formats reduces the activity at the current price, it invites changes of the bid function as a whole while the auction proceeds. However, we still observe less activity in the sequential auctions. Comparing item A and B, and aggregate demand revealed and not revealed, we see about the same pattern as in Figure 4.4: end peaks at the item B clock, and in particular when aggregate demand is revealed.

4.6 Results on Main Hypotheses

Our main hypotheses, based on economic theory and previous experimental results, were stated in Section 3.3 and are relisted here:

1. Single vintage: lower prices with open clock. In the single vintage case and with two vintages auctioned sequentially, clock auctions with aggregate demand revelation lead to lower prices (higher bid shading) than clock auctions without aggregate demand revelation or sealed bid auctions, which are similar.
2. Multiple vintages: lower prices with clock. If two vintages are auctioned simultaneously, a clock auction with aggregate demand revelation leads to lower prices than a clock auction without aggregate demand revelation which in turn leads to lower prices than a sealed bid auction.

3. Better price discovery with open clock. Prices are closer to Walrasian equilibrium and less volatile when using a clock auction with aggregate demand revelation than when using a sealed bid auction.
4. Higher efficiency with simultaneous auctions. If two vintages are to be auctioned off, then a simultaneous auction yields a more efficient allocation than a sequential auction.
5. Secondary market increases efficiency. If secondary markets exist, the allocation after trading is more efficient than the allocation before trading on the secondary market.

We do not find evidence for Hypotheses 1 and 2. We cannot detect significantly higher amounts of bid shading in the clock auction than in a sealed bid auction. All three tested auction types perform rather similar with respect to efficiency, auction revenues and bidder profits, in all employed auction environments (single vintage, two vintages auctioned sequentially, two vintages auctioned simultaneously).

We find some support in favour of Hypothesis 3. While prices are not different across auction formats and thereby not closer to the Walrasian equilibrium price, we observe lower volatility of prices across the auctions per experiment session if an open clock format is used rather than a closed clock or a sealed bid format. The differences are statistically significant for prices of item A in single-vintage and simultaneous two-vintage auctions.

One of our strongest results is obtained with respect to Hypothesis 4: _There is no evidence that a simultaneous auction of two vintages yields higher efficiency than a sequential procedure. Quite to the contrary, we even obtain some indication that a sequential auction yields more efferent allocations, higher auction revenues and better price signals (closer to Walrasian equilibrium prices). We thus have to reject Hypothesis 4.

Finally, we find no evidence in our data supporting Hypothesis 5, stating that a secondary market conducted after the allocation auction improves the allocation of permits. Rather, a subsequent secondary market seems to affect behaviour in the auction towards less aggressive bidding and thereby lower prices and revenues.

Figure 4.4: Load profiles/changes of bid quantity at current price

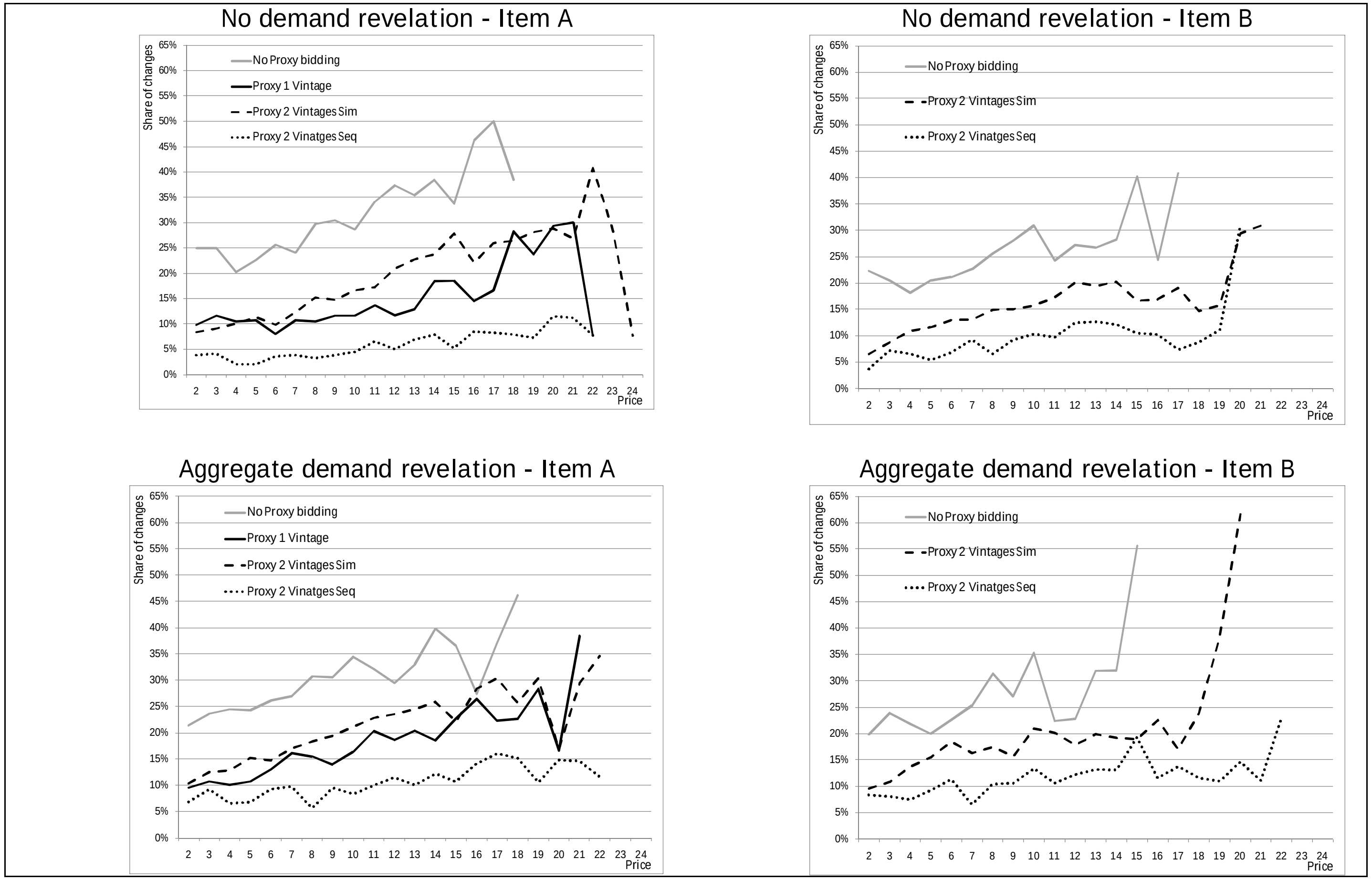
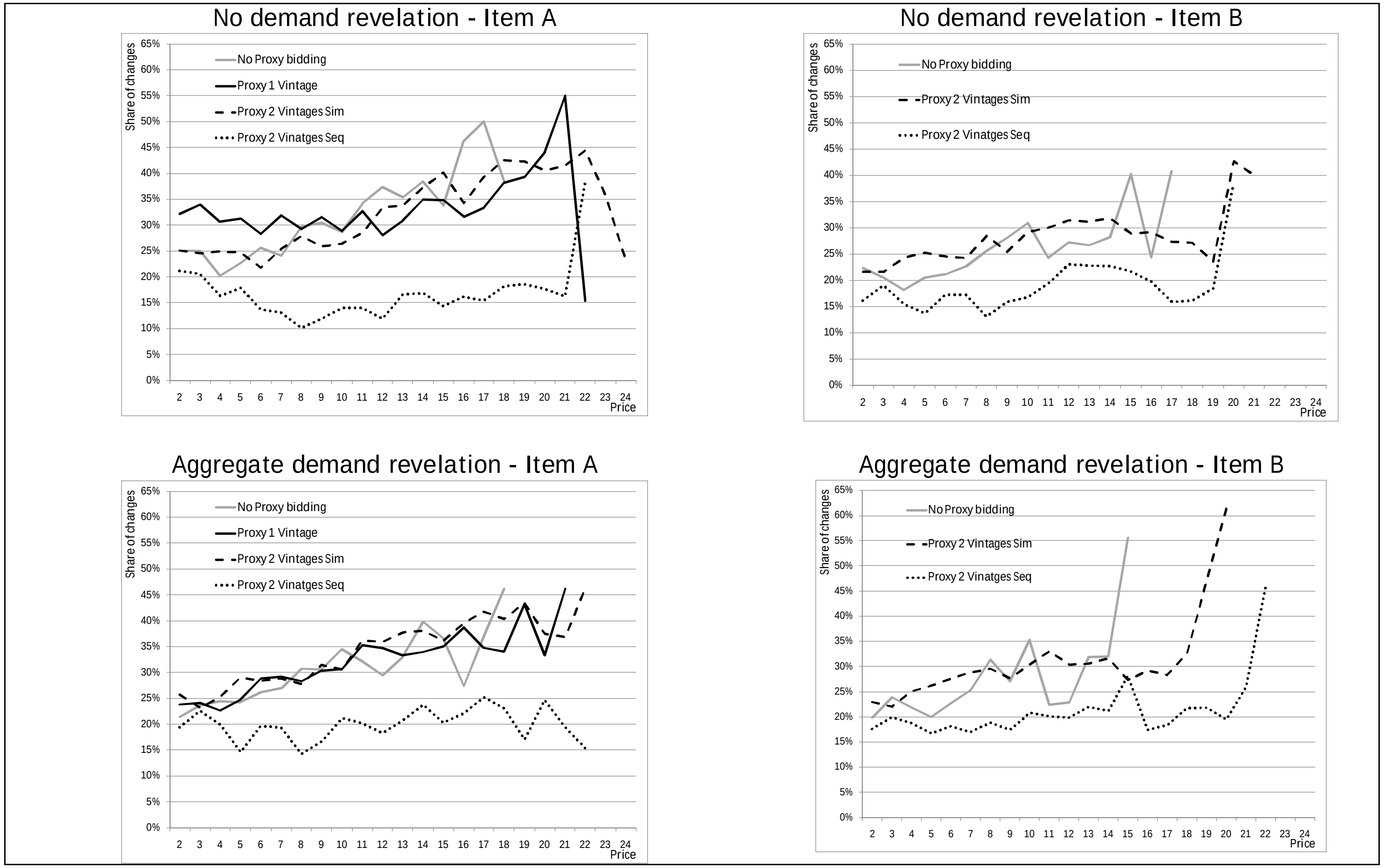


Figure 4.5 Load profiles/changes of proxy bid function for current and future prices



4.7 Overview of Performance Measures in all Experimental Sessions

Table 4.10: Session averages of auction efficiencies, auction revenues and bidder surpluses, relative to Walrasian benchmark

	Treatment															
						6		7						12		
	1	2	3	4	5	bef SM	afterSM	befSM	afterSM	8	9	10	11	befSM	afterSM	13
Relative auction efficiency																
Session 1	95.5%	97.2%	92.9%	94.2%	94.7%	89.7%	90.6%	91.9%	93.1%	94.3%	94.0%	89.9%	92.3%	90.6%	90.8%	95.1%
Session 2	96.6%	96.3%	96.1%	93.8%	97.0%	94.3%	92.8%	92.7%	92.2%	97.0%	95.8%	91.3%	97.4%	91.1%	88.6%	91.9%
Session 3	97.5%	88.5%	95.1%	96.5%	96.7%	96.0%	96.6%	96.6%	92.4%	94.1%	95.5%	91.7%	97.3%	94.4%	96.3%	95.3%
Session 4	97.2%	90.9%	95.8%	87.8%	88.9%	89.1%	86.3%	87.9%	91.0%	87.1%	87.0%	86.1%	87.2%	89.0%	86.4%	
Session 5	99.2%	94.4%	98.3%	83.0%	78.5%	81.4%	80.5%	80.8%	80.1%	82.2%	82.6%	81.3%	83.7%	80.5%	82.0%	
Session 6	90.2%	94.3%	93.8%	76.9%	74.6%	77.2%	75.9%	75.1%	77.2%	78.0%	75.0%	75.1%	78.8%	75.8%	78.2%	
Relative auction revenue																
Session 1	91.7%	87.5%	85.4%	87.4%	74.0%	72.7%		84.2%		92.8%	87.2%	73.6%	90.6%	79.1%		92.4%
Session 2	86.2%	91.5%	86.3%	77.1%	91.7%	77.3%		62.5%		89.8%	92.6%	73.8%	96.0%	68.1%		95.3%
Session 3	89.6%	102.1%	91.7%	86.3%	88.5%	87.4%		95.5%		90.4%	77.5%	85.5%	88.7%	75.0%		88.3%
Session 4	87.1%	80.7%	91.3%	79.3%	82.7%	77.8%		72.0%		83.3%	98.2%	71.0%	93.8%	86.1%		
Session 5	93.8%	89.6%	95.8%	77.1%	97.2%	80.2%		82.4%		94.4%	89.7%	94.9%	88.7%	64.5%		
Session 6	76.1%	75.8%	85.3%	90.5%	87.7%	86.5%		85.9%		93.3%	87.0%	80.1%	97.6%	84.6%		
Relative bidder surplus																
Session 1	109.7%	132.0%	120.1%	123.2%	184.2%	164.8%	169.9%	128.3%	134.1%	100.3%	122.9%	159.0%	97.3%	145.2%	144.6%	111.6%
Session 2	150.6%	126.7%	149.9%	186.1%	127.5%	186.3%	177.3%	256.5%	254.0%	136.2%	114.4%	184.4%	103.2%	217.6%	201.2%	116.7%
Session 3	131.6%	30.5%	109.9%	140.3%	131.7%	133.2%	136.9%	100.0%	76.5%	109.0%	174.0%	117.7%	133.7%	176.8%	186.9%	125.0%
Session 4	149.0%	142.2%	116.3%	130.5%	120.2%	147.9%	129.6%	166.6%	184.3%	105.7%	33.5%	159.9%	51.3%	100.9%	86.7%	
Session 5	119.8%	112.7%	107.3%	104.7%	9.7%	85.2%	81.1%	74.9%	72.6%	37.8%	57.4%	32.8%	65.2%	138.6%	146.2%	
Session 6	147.1%	165.9%	128.2%	26.3%	21.3%	42.4%	35.7%	32.4%	42.9%	19.1%	30.1%	57.9%	4.9%	38.0%	50.1%	

Table 4.11: Session averages of prices relative to Walrasian price, and price variances in sessions

	Treatment												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Relative price of item A													
Session 1	0.92	0.88	0.85	0.96	0.74	0.76	0.88	1.02	0.94	0.80	1.00	0.82	1.03
Session 2	0.86	0.92	0.86	0.78	0.95	0.81	0.67	0.93	1.04	0.79	1.02	0.74	1.04
Session 3	0.90	1.02	0.92	0.90	0.92	0.92	1.00	1.00	0.92	0.92	0.94	0.83	0.97
Session 4	0.87	0.81	0.91	0.83	0.87	0.85	0.78	0.91	1.09	0.78	1.00	0.91	
Session 5	0.94	0.90	0.96	0.85	1.02	0.85	0.90	1.02	1.02	1.00	0.94	0.75	
Session 6	0.76	0.76	0.85	0.96	0.91	0.93	0.89	1.00	0.96	0.87	1.02	0.89	
Relative price of item B													
Session 1				0.76	0.74	0.68	0.79	0.80	0.78	0.65	0.77	0.75	0.79
Session 2				0.76	0.88	0.73	0.56	0.85	0.78	0.67	0.89	0.60	0.83
Session 3				0.81	0.84	0.82	0.90	0.78	0.58	0.78	0.82	0.64	0.77
Session 4				0.75	0.77	0.69	0.63	0.73	0.84	0.62	0.86	0.80	
Session 5				0.66	0.90	0.74	0.73	0.85	0.73	0.88	0.82	0.50	
Session 6				0.83	0.84	0.78	0.82	0.84	0.75	0.71	0.92	0.79	
Variance of relative price of item A within session													
Session 1	0.003	0.005	0.026	0.002	0.007	0.003	0.001	0.001	0.011	0.015	0.009	0.030	0.002
Session 2	0.000	0.005	0.002	0.011	0.003	0.008	0.016	0.003	0.003	0.016	0.005	0.018	0.001
Session 3	0.001	0.001	0.003	0.001	0.003	0.003	0.010	0.003	0.017	0.003	0.001	0.007	0.002
Session 4	0.001	0.141	0.000	0.004	0.002	0.001	0.001	0.003	0.004	0.010	0.004	0.011	
Session 5	0.001	0.001	0.002	0.008	0.001	0.001	0.005	0.005	0.005	0.014	0.001	0.003	
Session 6	0.003	0.001	0.008	0.001	0.017	0.003	0.012	0.003	0.001	0.001	0.001	0.008	
Variance of relative price of item B within session													
Session 1				0.011	0.008	0.006	0.011	0.007	0.009	0.005	0.022	0.029	0.007
Session 2				0.004	0.006	0.006	0.010	0.002	0.006	0.012	0.009	0.016	0.001
Session 3				0.006	0.005	0.005	0.017	0.007	0.015	0.004	0.003	0.009	0.001
Session 4				0.015	0.003	0.006	0.001	0.001	0.001	0.006	0.003	0.022	
Session 5				0.009	0.005	0.036	0.009	0.011	0.009	0.007	0.003	0.021	
Session 6				0.012	0.007	0.002	0.006	0.002	0.006	0.008	0.000	0.023	

5. Discussion of Findings

The *White Paper* recommends an open clock auction (with revelation of aggregate demand at the end of each round) for the initial allocation of CO_2 emissions permits in the Australian CPRS. If multiple vintages are auctioned at the same time, simultaneous auctions are recommended. Further, the *White Paper* advises augmenting the auction with proxy-bids.

Our literature review in Chapter 2 shows that the recommended design is not common for auctions of emissions permits. Typically, sealed bid auctions are used in this context. Moreover, if multiple vintages are auctioned in the same event, they are conducted sequentially rather than simultaneously.

Against this background, our experimental study described in Chapter 3 tests the *White Paper*'s proposal by means of a laboratory experiment. Chapter 4 shows that the results of the experiment are not absolutely clear cut. All auction types perform similarly well with regard to allocative efficiency, price discovery, and auction revenues. In many cases, there are only marginal differences, which are statistically not significant, between individual treatments.

In this Chapter we relate our experimental results to the findings in the literature and experiences in practice. Our recommendations are based on the joint evidence from the literature and our experiment, and are presented in Chapter 6.

5.1 Auction Type: Sealed Bid vs. Clock

Literature

The literature review in Chapter 2 suggests that clock auctions might have better price discovery properties, and, therefore, might be advantageous in trading schemes where functioning secondary markets do not (yet) exist. Moreover, due to the informational feedback they provide in each round, open auction formats are generally believed to be easier to understand.

If, to the contrary, functioning secondary markets exist in which both spot and future products are traded, the need to create further price signals in the auction becomes less important. For this reason some authors favour sealed bid auctions, as a sealed-bid format makes collusion more difficult. This holds in particular for periodical auctions with the same bidders. In such a repeated game, collusion among bidders becomes more likely. Collusion will not only result in lower revenues for the Government, but will also distort the price signals to secondary markets and would be likely to yield inefficient allocations of permits.

Previous experimental studies, however, did not find differences in efficiency between sealed bid and clock formats. One study (Porter et al. 2009) found that the ascending clock design generates higher revenues than discriminatory sealed bid auctions if demand is elastic, but lower revenues in inelastic environments.

A disadvantage of sealed bid auctions for multiple vintages is the risk of inconsistent price structures. If permits can be transferred into future years, earlier vintages cannot be worth less than later vintages. This should be reflected in the price structure resulting from any auction. In principle, bid sorting algorithms can effectively address this problem. With deferred payment arrangements, however, nominal prices are distorted due to discounting, and thus bid sorting cannot be applied in the Australian CPRS.

Finally, sealed bid auctions have advantages from a practical perspective since the submission of bid schedules needs not to be synchronized, and the auction itself is extremely fast once the schedules have been submitted. Thus, a sealed bid auction is process-efficient and minimizes transaction costs.

Experiment

In our experiment we do not find a significant difference in terms of efficiency between clock and sealed-bid auctions, either in the non-parametric tests or in the regression analysis[24]. Also the regressions, that take into account multiple independent variables, do not indicate higher efficiency of the clock compared to the sealed bid auction.

One should keep in mind, however, that the experiment did not feature uncertain value components. In actual applications, bidders may not know their exact abatement costs or the (future) market prices of the permits. In contrast to the sealed bid auction, the clock auction deals with these uncertainties by its better price discovery properties. Therefore, we still expect clock auctions to perform better than sealed bid auctions, if traders face uncertainties regarding the value of the permits.

With respect to the aggregation of information, we find that the prices in open clock auctions tend to be closer to the Walrasian benchmark[25] than in sealed bid auctions[26]. Thus, the fear that clock auctions lead to more collusion and thereby lower prices and efficiency seems not be warranted, based on the results in our experimental environment with 14 bidders and no communication.

We also do not observe a trend of decreasing revenues over time in the open clock auctions. Thus, there is no evidence that bidders learn to collude over the sequence of the auctions.

Conclusion

Our results are consistent with the literature (Holt et al. 2007, Porter et al. 2009) in not detecting significant efficiency effects of using a sealed bid auction compared to an open clock auction. Neither do we find evidence for higher bid shading or more collusion in clock auctions. Thus, using the price discovery advantage of clock auctions seems to be appropriate, in particular at the start of the CPRS.

5.2 Information Revelation in Clock Auction: Revealing vs. Not Revealing Aggregate Demand

Literature

While Kagel and Levin (2001) find higher efficiency in clock auctions if aggregate demand is revealed, Holt et al. (2008) warn that demand revelation might facilitate collusion and demand reduction. However, not revealing the aggregate demand in a single vintage auction (and also in sequential auctions) makes the clock auction strategically equivalent to the sealed bid auction. Only if multiple vintages are auctioned simultaneously, sealed bid and clock auctions in which aggregate demand is not revealed might differ from a theoretical perspective.

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[24] A significant positive effect of a open clock format is only found for the isolated comparison of the treatments with simultaneous auctions of two vintages.
[25] See Section 4.1 for a definition of Walrasian equilibrium and Walrasian prices as performance benchmarks.
[26] Exceptions are prices in the single-vintage treatments as well as prices for item B in the two-vintages treatments.

Experiment

Looking at averages of our parameters of interest (efficiency, prices, revenues, bidder surpluses) we observe that the clock auction performs slightly better if demand is revealed. This observation, however, is not supported by statistics as in none of our non-parametric tests or the regression analysis a significant difference between the two rules of information revelation is found.

Conclusion

Our experiment does not find evidence for Holt et al.'s concern regarding higher collusion when demand is revealed. We find some indication for Kagel and Levin's classic result of higher efficiency with aggregate demand revealed in the clock auction, but cannot report sufficient statistical support.

5.3 Proxy Bidding

Literature

In consumer auctions proxy bidding has become very common. However, we are not aware that proxy biding has been applied in permit auctions, yet. Proxy bidding has many potential advantages by combining the features of a sealed bid and a clock auction and giving the bidders the opportunity to choose the format which best serves their needs. However, proxy bidding may also result in higher complexity of both auction rules and the auction interface.

Experiment

First pilot sessions indicated that the way proxy bids are elicited might have an impact on auction efficiency. We first implemented proxy bidding such that bidders were asked to submit marginal bids in blocks of permits. For transparency we calculated and displayed the full bidding function based on these marginal bids. However, participants had difficulties understanding this process. Our observations suggest that the notion of a bid as an absolute quantity is easier to capture than the disaggregated notion of marginal bids. Whether this holds in general or not, the issue underlines the importance of sufficient bidder training in any auction design. In our final experimental design, bidders submitted their proxy bid schedule in terms of absolute quantities as a function of future prices.[27] The proxy bidding option was heavily used. As expected, its existence led to less bidding activity at current auction prices, but due to the possibility of also altering the bidding schedule for future prices, the overall auction system load was similar to the auctions where no proxy bidding was offered.

Conclusion

We recommend providing the opportunity for proxy bidding, but advise care be taken to design an intuitive, easy-to-use bidding interface and to provide sufficient bidder training (e.g. a mock auction test site).

5.4 Intra-Round Bidding

Literature

Intra-round bidding has been proposed in the literature (Ausubel et al. 2006) for clock auctions to reduce overshooting and to smooth price discovery. However, it may also add to the complexity of the auction. If a proxy bidding mechanism exists, intra-round bidding can be implemented as a free-form of proxy bids. Therefore, in conjunction with proxy bidding, intra-round bidding should be easy to implement.

[27] The specific design is explained in Chapter 3 of this report.

Experiment

We have not allowed for intra-round bidding in the experiment. Therefore we do not have results to judge its performance.

Conclusion

If the auction is implemented similarly to the experiment, then intra-round bidding can be easily implemented by allowing proxy bids over self-defined price steps. Considering the advantages of reduced overshooting and a smoothed price discovery, we recommend implementing this option.

5.5 Sequence of Auctioning Multiple Vintages: Simultaneous Auctions vs. Sequential Auctions

Literature

One prominent conjecture in the market design literature is that simultaneous procedures outperform sequential procedures whenever the values of multiple auctioned items are related, either as substitutes or as complements. The different vintages of the CPRS can be best described as substitutes (an earlier vintage is a perfect substitute of a later vintage; given the restricted borrowing the reverse, however, is not true). The advantage of the simultaneous approach is that it allows bidders to shift demand from one vintage to another during the course of the auction. This gives bidders the flexibility to react to price differences and to adjust their demand accordingly. By this flexibility, the simultaneous format facilitates more efficient outcomes.

Experiment

Unexpectedly, we do not find the simultaneous auctions to be more efficient than the sequential auctions in our experiment. In particular, we do not detect statistically significant differences between simultaneous and sequential auctioning with respect to allocative efficiency when using non-parametric tests. To the contrary, our regression analysis even finds a positive effect of auctioning sequentially rather than simultaneously.

More evidence stems from the analysis of prices and revenues. Sequential auctions of multiple vintages (as opposed to simultaneous auctions) yield higher prices and correspondingly result in higher seller revenues.

Conclusion

Our experimental results contradict the theoretical presumption that simultaneous auctions yield higher efficiency than sequential auctions. We do not find support for this claim, our results even point into the opposite direction. A reason might be that the sequential procedure is not as complex as the simultaneous format. Considered individually, the two consecutive single auctions are straightforward and easy to understand. Thus, our experimental results indicate that a sequential auction format would be a reasonable choice, in particular if ease of use and simplicity are relevant aspects for the auctioneer.

5.6 Order of Sequence if Auctioning Sequentially

Literature

Economic theory suggests that auctions yield higher revenues if the good with the more dispersed buyer valuations is auctioned first (Bernhardt and Scoones, 1994). Most likely, in the CPRS context, this is the earlier vintage because short-term abatement costs depend on the individual situations of companies whereas prices of future permits are based on long-term abatement costs (which depend e.g. on technology advancements) or the relevant (expected) secondary market price.

The empirically observed declining price anomaly in sequential auctions might result in price inversions if more valuable items are auctioned later. To prevent this, vintages should be auctioned in the sequence of their valuations, starting with the most valuable vintage. This even holds with transitional deferred payment arrangements as deferred payment only impacts nominal prices, but not the fundamental values of the permits of different vintages[28].
Finally, it is best practice in international permit auctions to sell earlier vintages first (cf. e.g. RGGI and NOx auctions). In the long run, when functioning secondary markets exist, the sequence of auctioning for vintages will become less important.

Experiment

We did not test different sequences in our experiment. In the experiment item A was always at least as valuable as item B, and we always auctioned first item A and then item B. A price reversal was observed in less than 1% of the clock auctions. In the sealed bid auctions, inverse price structures were prevented by the application of a bid sorting rule (see Chapter 2 and below for more details on these rules).

Conclusion

Our experiment does not provide new insights with respect to the appropriate sequencing of permit auctions. We therefore follow the literature and the practice in other trading schemes, and recommend auctioning the earlier vintage first. This recommendation is backed by theory if valuations of earlier vintages are more dispersed than future vintages, which we consider likely in the Australian CPRS.

5.7 Reserve Prices

Literature

As pointed out in the comprehensive discussion in Section 2.2.6, reserve prices in auctions have been discussed mostly in the theoretical rather than empirical or experimental literature (e.g. Myerson 1981, Riley and Samuelson 1981). Theory predicts that appropriate reserve prices may prevent collusion, speed up the auction, and increase (expected) revenues. McAfee and McMillan (1987), however, point out that inefficient outcomes are likely if not all items are sold. Also, recall the discussion on the optimal level of a reserve price and its disclosure.

Experiment

We did not test different reserve prices. Our effective reserve price in all our experimental auctions was E$1, and the final auction prices always exceeded this benchmark.

[28] If payment for later permits is deferred to that later date it may well be that the nominal price of the later vintage exceeds the price of the earlier vintage even though the earlier vintage is more valuable. Proper discounting of the price to be paid in the future restores the ranking of values.

Conclusion

The experiment does not provide further insights with respect to optimal reserve prices. Based on the literature, we recommend setting a reserve price which balances the risk of low revenue due to incentives for demand reduction with the risk of not selling all permits. In the absence of a secondary market price, we recommend setting the reserve price either at $10 per AEU (i.e. equal to the fixed price in the year 2011/12) or at a percentage of a model price (if adequate models exist). When mature secondary markets have developed, the reserve price should be linked to the market price (percentage of the secondary market price). To be flexible, the auction regulation should only refer to the authority which is in charge of setting and revealing the reserve price, and should not specify any further details.

The question of whether the reserve price should be published or not is more relevant to non-recurring private auctions than transparent public auctions on a regular basis. In the latter case, permanent non-disclosure of the reserve price (or the method by which it is determined) is neither likely nor recommended. As shown in Table 2.1 the majority of existing auctions reveal the reserve price. Only Ireland (with only 2 auctions) and the UK have not been publishing the reserve price. However, the UK has published the calculation method.

Following the example of Austria, we recommend publishing the reserve price 2 weeks prior to the auction.

5.8 Minimum Bid Size/Parcel Size

Literature

In Chapter 2 we reviewed common parcel sizes in different markets . Large contract sizes may prevent small bidders from participating and may lead to low competition in the auction. (In Germany, for example, the minimum bid size for forward units is 1,000 EUAs, and in one auction only six bidders participated.) In other markets, such as financial markets, more finely grained parcel sizes are common.

Experiment

We did not test different parcel-sizes experimentally.

Conclusions

Up to small rounding effects, the parcel size (minimum contract size) does not impact the bidding strategy, the allocation, or the resulting prices of an auction. However, a finely grained parcel size has the advantages of a low entrance barrier and high flexibility. For this reason we recommend a parcel size of 1 AEU.

5.9 Micro Rules

The experiment aimed at testing whether the micro-rules which have been discussed in the literature and used in other large scale auctions (pricing, allocation of excess supply, activity rule), or developed for our experiment (bid sorting and switching), work in an experimental setting. The experiment was not set up to compare different micro rules against each other. The employed micro rules are discussed in detail in Chapter 2; algorithmic descriptions are given in Chapter 6 and the Appendix.

The following micro rules were employed in the experiment:

Pricing

Permits of the same vintage were uniformly priced with the price determined by the lowest accepted bid (LAB) (as opposed to the highest rejected bid).

Allocation of excess supply

Excess supply was proportionally allocated. Non-integer fractions were rounded according to the largest remainder method.

Activity rule

The total demand of a bidder was not allowed to increase from one round to the next. If multiple vintages were auctioned, bidders could switch demand, i.e. increase demand for one vintage if they decreased demand for the other vintage by at least the same amount.

Switching

Before the close of an auction round, switching was not limited. However, switching was adjusted ex-post by a proportional reduction of the switch if total demand for one item would otherwise have dropped below the supply. In the latter case, the switch was automatically reduced after the round so that a complete allocation of the supply was ensured.

Bid sorting

Random marginal values were induced which were at least as high for item A as for item B. In order to avoid price reversals, bids were automatically sorted in simultaneous sealed bid auctions if necessary. The sorting algorithm was an extended version of the rule proposed by Holt et al. (2008).

Literature

The literature does not give unambiguous recommendations regarding the above micro rules. With respect to pricing, LAB rules are far more common, but are challenged (e.g. by Sujarittanonta and Cramton, forthcoming). However, with respect to the particular case of emission permit auctions, the impact of the pricing rule is negligible, since in auctions with many items the prices according to the highest losing and the lowest winning bid will be different only in the case that in the last bidding round aggregate demand exactly equals aggregate supply. Proportional allocation of excess supply is best practice in many other applications (e.g. central bank auctions). Regarding activity rules, the existence of a proper rule is more important than its precise design. Many actual auctions even apply rather weak versions with eligibility levels far below 100% (e.g. FCC or forthcoming German spectrum auction). Switching and bid sorting rules are relatively new and we are not aware that they have been experimentally investigated prior to our study.

Experiment

All micro rules worked well in the experiment and no problems were detected. This also holds for the rather new rules with respect to switching and bid sorting. The former was performed in the last rounds of 47 of 96 simultaneous clock auctions, and the latter applied in 5 of the 48 simultaneous sealed bid auctions.

Conclusion

As the above micro rules performed well in the experiment, the uniform LAB pricing rule, the proportional allocation of excess demand, and the activity rule are recommended for the Australian CPRS. Bid sorting is not relevant for an open auction[29]. With respect to shifting demand from one vintage to another vintage, the switching rule with ex-post adjustments worked well and, thus, can also be applied. Note, however, that alternatives were not tested.

[29] Due to the option of deferred payment, bid sorting could not be applied even in a sealed bid auction, as the nominal and real values of vintages do not follow a clear and unambiguous order at the time of the auction.

Unrestricted switching with ex-post adjustments was applied in the experiment as it allowed for a homogeneous user interface in all treatments and thus facilitated comparability. In actual applications, the determination of "temporarily assigned quantities" and "free bidding rights" at the end of each round is also a valid option (see our discussion in Chapter 2).

6. Recommendations

6.1 Summary of Recommendations

As a result of our discussion in Chapters 4 and 5 we make the following recommendations for the CPRS auction design:

The auctions:

4. Should apply the format of a clock auction with proxy-bidding, and
5. Should reveal aggregate demand after each round (which we call open clock auction), and
6. Should be sequential if more than one vintage is auctioned at an auction event, with the earliest vintage auctioned first.

Once liquid secondary markets are in place, it is suggested that switching to sealed bid auctions be considered[30]. The performance of the sequential auctions should be reviewed. If performance is low (i.e. auction prices deviate from the prices on the secondary market), a change towards simultaneous auctions should be considered[31].

Regarding further auction details, we make the following recommendations.

Contract size:
A small minimum contract size of 1 AEU is recommended.

Reserve price:
A reserve price larger than zero is recommended for the auction (see discussion in Chapter 2.2.6 and Chapter 5). Guidelines are provided in the reasons below.

6.2 Main reasons for Our Recommendations

6.2.1 Auction Type

The experiment did not reveal significant differences with respect to the efficiency of the final allocation between clock and sealed-bid auctions[32]. Thus, other characteristics of the auction formats become important for recommending an appropriate auction design.

An emission trading scheme is efficient if the economy's total abatement costs are minimized. In order to identify the appropriate abatement measures, accurate information on the economy's marginal abatement costs is necessary. In well functioning markets, permit prices, both for spot and future vintages, will reflect these costs and will give valuable support for decisions on investments in abatement measures. In the initial phase of the CPRS, in which a functioning secondary market may not have evolved, it is particularly important that the auctions generate price signals that are close to the actual abatements costs. Thus, the price discovery properties of the clock auction become an important feature.

[30] In this respect, secondary markets can be considered liquid if significant volumes are being traded and if price fixings occur at least on a daily basis.
[31] Note that nominal price reversals per se do not necessarily point to low performance of a sequential auction. Higher prices of a later vintage could be justified by discounting due to deferred payment.
[32] A significant difference between open clock and sealed-bid auctions can only be found in our non-parametric tests for the treatments with simultaneous auctions. Here, the open clock performed better than the sealed-bid format.

As those characteristics can only be fully exploited if the aggregate demand is revealed in each round, and as we do not find any evidence for collusion or higher bid shading when the aggregate demand is revealed, we conclude that an open clock auction is the appropriate design for the initial allocation auctions under the CPRS.

In the experiment, sequential auctions performed slightly better than simultaneous auctions in terms of how close final prices are to the benchmark of Walrasian prices[33]. We do not find the sequential auctions to be less efficient than simultaneous auctions; our results even indicate positive efficiency effects of auctioning sequentially. This contradicts the theoretical presumption. Apparently, the expected advantage of a simultaneous over a sequential auction procedure might not exist in actual applications. A reason might be that the sequential procedure is not as complex as the simultaneous format, and thus straightforward bidding strategies are more obvious. With simultaneous auctions, complexity increases in terms of the additional micro rules regarding demand switches as well as with respect to the information bidders have to process before they bid. Considered individually, the two consecutive single auctions are straightforward and easy to understand. Also, from the perspective of the auctioneer, if ease of use and simplicity are relevant aspects of the auction, a sequential format should be considered.

In sequential auctions, generally the item with the more dispersed valuations should be auctioned first (see our discussion in Chapters 2 and 5). Moreover, empirically, declining prices are persistently observed in sequential auctions (declining price anomaly or afternoon effect). Even though this effect refers to homogeneous products, it is of relevance for the Australian CPRS because limited borrowing is allowed. If a bidder buys a permit of a later vintage in an early auction, intending to use it prior to the vintage of the permit (borrowing), and if he pays a price which is higher than the price of permits in later auctions, prices are reversed. These price reversals are less likely if the earlier vintage is auctioned first (see also Section 2.3.4 for more details including a comment on the impact of deferred payment).

We conclude:

- Open clock auctions should be conducted.
- As simplicity of the auction procedure is a major criterion for the design of public auctions, sequential auctions should be used when multiple vintages are auctioned. In those auctions, the earliest vintage should be auctioned first.

6.2.2 Contract Size

A small minimum contract size of 1 AEU gives the bidders the most flexibility and supports small bidders (see discussion in Chapter 2.2.7). Note that the contract size does not affect the computational or data processing complexity.

6.2.3 Reserve Price

An aggressive reserve price (i.e. a reserve price which is not much lower than the final closing price) speeds up the auction and reduces the incentives for demand reduction in multi-unit auctions. Hence a rather high reserve price also contributes to allocative efficiency.

Once a secondary market exists, the price of permits in this market can serve as a guideline for the reserve price. Such an approach has been adopted by other systems (e.g. RGGI, Austria; see Table 2.1 in Chapter 2 for more details). In these systems, the reserve price is set to a percentage of the secondary market price[34].

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[33] See Section 4.1 for a discussion of Walrasian equilibrium and Walrasian prices as performance benchmarks.

[34] Since market prices have been volatile in basically all trading systems, formulae for determining the reserve price have been rather defensive when taking longer historical periods into account (e.g. Austria). A more aggressive formula based on a shorter period is recommended. The length of this period could be linked to the frequency of the auctions. For example, the regulator could set the reserve price to 80% of the

In the initial phase, i.e. before liquid secondary markets have developed, the 2011/12 fixed price of $10 per AEU or a percentage of comparable international prices could be used as a starting point.

6.2.4 Permit auctions in a Mature Permit Trading Scheme

The main goal of a market-based approach for reducing CO_2-emissions is the generation of price signals which facilitate abatement at minimal total costs for society. In an initial phase of a cap-and-trade system, the allocation auctions should provide this price information. By contrast, in a mature emissions trading scheme with functioning secondary markets at which both spot and future products are traded, there is no need to create further price signals by allocation auctions.

Moreover, periodical auctions with the same bidders take on the characteristics of a repeated game. In such a situation, collusion among bidders becomes more likely. Collusion will not only result in lower revenues for the government, but is also likely to yield inefficient allocations and reduce the quality of the price signal.

Since sealed bid formats are generally considered to be more robust against collusion, we suggest that a shift from the open clock to a sealed bid format be considered once secondary markets have evolved. Sealed bid auctions also have advantages from a practical perspective, since the submission of bid schedules need not be synchronized, and the auction itself is extremely fast once schedules have been submitted. Thus, a sealed bid auction is process-efficient and minimizes transaction costs. This is certainly one of the reasons why sealed bid formats are common practice in other large-scale auctions that are run on a regular basis, not only in the context of emissions permits, but also, for example, in central bank auctions.

Under the sealed bid format, simultaneous auctions of multiple items are less complex than under an open format, since bidders cannot shift demand between items from round to round. In addition, by the time secondary markets have evolved, participants should be familiar with multi-item permit auctions, such that the argument of the simplicity of the sequential auction becomes less important. Rather, efficiency and revenue generation should be the main criteria, and the risk of strong demand reduction or even collusion should be minimized. Note, however, that in the experimental data we do not observe a trend of decreasing revenues in the open auctions over the sequence of rounds, and the experimental sealed bid treatments do not generate higher revenues than the open auctions[35].

We conclude:

- Once functioning secondary markets have evolved, a shift to sealed bid auctions is recommended, at least for single-vintage auctions.
- For auctions of multiple vintages, the initial sequential procedure should be reviewed after two to three years, and a switch to a simultaneous auction format re-evaluated.

weighted average of the last three months' market price if auctions are held quarterly, and to 85% of the weighted average of the last month's market price if auctions are run monthly.[Suggested highlighted text could be moved out of footnote to main text.].

[35] With deferred payment, bid sorting algorithms, which improve the efficiency of a sealed bid auction by avoiding inverted price structures, are no longer feasible.

6.3 Detailed Description of Recommended Auction Design

In this section we describe details of the recommended auction design. The presentation applies a more formal approach and aims to clearly define particular rules with respect to auction procedure, pricing and allocation of items. The material is intended for readers with interest in technical details (e.g. software programmers), and the section abstracts from an actual application (such as auctions for emissions permits), but provides illustrative links to the Australian CPRS or the experiment of this study.

6.3.1 Notation

In the following we consider an auction situation in which *s* units of an item are auctioned. The quantity *s* of available units is also called the *supply*. There are *n* bidders participating in the auction, and the set of bidders is denoted by

$N = \{1, 2, \ldots, n\}$.

To simplify the later description, we introduce notions of a *marginal bid*, a *bid schedule*, and a bidder's *demand* at a particular price, as well as the *demand function* of a bidder. A *marginal bid* (*p*, *q*) is characterized by a price *p* and a quantity *q*. It indicates the willingness of the respective bidder to acquire up to *q* units of the item if the price is not larger than *p*. In the auction, a bidder does not submit a single marginal bid, but defines a *bid schedule* (the bid schedule is also referred to as a *bidding plan*) which consists of a set of l_i marginal bids. Thus, the bid schedule (bidding plan) of a bidder $i \in N$ is given by the set

$$B_i = \{(p_{i,1}, q_{i,1}), (p_{i,2}, q_{i,2}), \ldots, (p_{i,l_i}, q_{i,l_i})\} .$$

Example (Bid Schedule):

Assume the bid schedule of company *A* for permits of the vintage 2015 is

B_A^{2015} = { (\$20, 30*t*), (\$15, 20*t*), (\$8, 4*t*) } .

This means that company *A* is willing to buy permits for 30 *t*, if the price is not higher than \$20 but above \$15. If the price is higher than \$8, but not higher than \$15, the company would buy permits for up to 30 *t* + 20 *t* = 50 *t* and if the price is \$8 or less, company *A* is willing to buy up to 30 *t* + 20 *t* + 4 *t* = 54 *t*.

Note that the term *marginal bid* refers to the format in which a (limit) order is usually submitted at stock exchanges, and the term *bid schedule* refers to a trader's order book in financial markets.

The joint set of bid schedules of all bidders constitute the aggregate bid schedule

$$B = \bigcup_{i \in N} B_i .$$

The demand of a bidder $i \in N$ at a price *p* is denoted by $d_i(p)$ and refers to the *total* quantity the bidder seeks to buy at this price. The demand can be calculated from the bidder's marginal bid schedule. The bidder's *demand function*, which maps any price *p* to his demand at this price, is given by

$$d_i(p) = \sum_{(p_{i,k}, q_{i,k}) \in B_i \,|\, p_{i,k} \geq p} q_{i,k}$$

(*k* just serves as an index to enumerate the bidder's marginal bids).

Example (Demand of a Bidder)

Consider, again, company *A* which is bidding for permits of the vintage 2015. As in the example above, the bid schedule of company *A* is

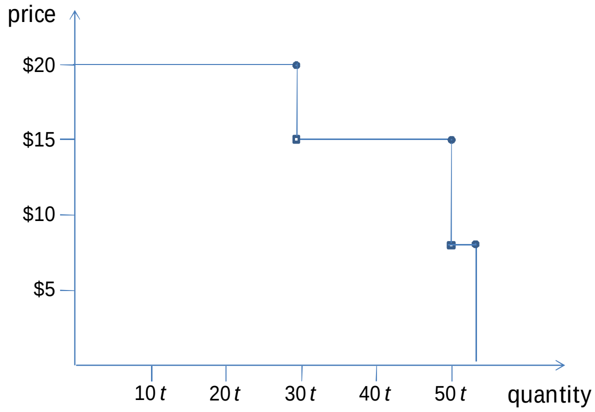
B_A^{2015} = { (\$20, 30*t*), (\$15, 20*t*), (\$8, 4*t*) } .

The demand function then calculates to

$$d_A^{2015}(p) = \begin{cases} 0t & \text{, if } p > \$20 \\ 30t & \text{, if } \$20 \geq p > \$15 \\ 50t & \text{, if } \$15 \geq p > \$8 \\ 54t & \text{, if } \$8 \geq p \, . \end{cases}$$

Figure 6.1 displays a graph of the demand function. As is usual in economics, the price is plotted along the ordinate and the quantity along the abscissa. The steps of the graph reflect the marginal bids.

Figure 6.1: Demand function of a bidder



Note that in an actual application, it makes no difference whether bidders specify a set of marginal bids or a demand function, as one can be computed from the other, and vice versa. As noted above, the notation in marginal bids is common in financial markets. However, the notion of a bidder's demand (i.e. the accumulated quantity of the respective marginal bids) is more natural in the context of a clock auction. Therefore, in our experiments, bidders' inputs were consistently in the form of demand functions.

The *aggregate demand* of all bidders at a particular price is the sum of the bidders' demand at that price. Thus, the aggregate demand function *D*(*p*) is given by

$$D(p) = \sum_{i \in N} d_i(p) \, .$$

6.3.2 Clock Auctions

In this section we introduce the general format of a clock auction. As a sequence of single-item multi-unit clock auctions is recommended, we restrict the presentation to single-item clock auctions. Therefore, there is no need for switching rules. An extension to multiple items (vintages) is included in Appendix A.

Auction Clock

In a clock auction, a so-called auction clock shows the current price at all times. The clock starts at a reserve price p_0 and bidders respond by specifying their demand $d(p_0)$

at this price. The reserve price constitutes the lowest possible price. If the aggregate demand at the reserve is smaller than the supply, the supply is not completely allocated.

If, however, the aggregate demand exceeds supply, the clock ticks forward by increasing the current price and, again, bidders respond by specifying their demand at the new price. This process continues as long as aggregate demand exceeds supply.

Formally:

The price increase from round t to the next round t+1 is given by an increment $\Delta > 0$, i.e.

$p_{t+1} = p_t + \Delta$.

To speed up the auction, the increment can also be set dynamically. In large scale auctions it is typical that the increment is set as a percentage of the current price, and the percentage decreases over time (e.g. 15% to 1.5% in the forthcoming spectrum auction in Germany). In the context of the Australian CPRS, the final price can be more accurately estimated, and a significantly lower number of rounds is expected.[36] Thus, absolute increments which are decreased over time seem reasonable.[37]

Activity Rule

In a clock auction, bidders may not increase their demand as the price of the clock rises.

Formally:

A bidder who demands $d(p_t)$ at a price p_t may not demand more than $d(p_t)$ in the further course of the auction, i.e.

$d(p_{t'}) \leq d(p_t) \; \forall \; t' \geq t$.

This activity rule is typical for multi-unit auctions. In the (non-clock) simultaneous multiple-round ascending auction, the number $d(p_t)$ is usually called a bidder's bidding rights. In any round a bidder cannot submit more bids (bid on more items) as he has bidding rights, and if he submits fewer bids than he has bidding rights, the bidding rights are reduced accordingly.

Stopping (or Closing) Rule

A clock auction lasts as long as aggregate demand exceeds supply.

Formally:

The auction lasts as long as $D(p_t) > s$ and stops if $D(p_t) \leq s$.

Pricing

A uniform pricing scheme is recommended in which the lowest price of a winning bid (also referred to as lowest-accepted-bid, LAB) determines the closing price of the auction. The closing price is the price which all bidders have to pay for all units of the item they receive.

Formally:

The closing price p^* of the auction is given by

$$p^* = \min_{D(p) \geq s} p$$

[36] The UMTS auction in Germany, for example, lasted over 173 rounds.
[37] The analysis of increment steps has not been a subject of this study. For an open clock auction with intra-round proxy-bidding, simple algorithms for the increment steps can be formulated. An example is to initially set the increment to AUS$ 1 per ton; once total demand drops below 125% of supply, the increment can be reduced to AUS$ 0.50 per ton and further reduced to AUS$ 0.25 per ton if aggregated demand drops below 110% of supply.

or the reserve price p_0 if $p_0 > p^*$.

Note that under the above LAB rule, the closing price is either the last or the second-to-last price shown by the auction clock. If at the end of the auction aggregate demand exactly equals supply, then the price of the item is set to the last price of the clock. If, however, in the last round aggregate demand is smaller than the supply, then the price of the item is set to the second-to-last price of the clock.

Allocation of Goods

If, at the end of the auction, aggregate demand equals supply, all bidders receive exactly the amount of their demand at the closing price. If the closing price of the auction is set to the second-to-last price, bidders receive their demand at the last price of the clock, and in addition a share of the residual supply in proportion to their unfulfilled residual demand at the closing price.

Formally:

If in the last round t^* the total demand exactly equals supply ($D(p_{t^*}) = s$), then each bidder i receives the quantity $d_i(p_{t^*})$ she has requested in his last bid. If, alternatively, total demand in the last round t^* is lower than the supply ($D(p_{t^*}) < s$), the final price p^* is set to the price of the second-to-last round t^*-1 ($p^* := p_{t^*-1}$). In this case $D(p_{t^*}) < s$, but $D(p^*) > s$, i.e. the demand at the closing price is larger than the supply and, thus, bids must be rationed.

Again, all bidders are awarded the quantity $d_i(p_{t^*})$ they have demanded in their last bid. In addition, the residual supply $s - \sum_i d_i(p_{t^*})$ is allocated to the bidders in equal proportions to the residual demand with respect to the bids $d_i(p_{t^*-1})$ in the second-to-last round. This means that a particular bidder j receives, in addition to $d_j(p_{t^*})$ units, an amount given by

$$\left(d_j(p_{t^*-1}) - d_j(p_{t^*})\right)\frac{s - \sum_i d_i(p_{t^*})}{\sum_i d_i(p_{t^*-1}) - \sum_i d_i(p_{t^*})}$$

If the above formula results in fractions smaller than the minimum contract size (i.e. 1 t), the values will be rounded such that the total supply is exactly allocated. In the experiment, we used the largest remainder method (also known as Hare-Niemeyer rule which is commonly applied in proportional representation voting).

Information Revelation

At the end of each round t, the aggregate demand $D(p_t)$ is revealed to all bidders. Since the aggregated demand is revealed after each round, the auction is referred to as an “open clock auction” in this report.

Proxy-bidding

In a clock auction with proxy-bidding, a bidder can instruct the computer to bid on his behalf rather than responding to each current price individually. The bidding rules for the computer are called proxy-bids and represent a bidder’s demand function (or schedule of marginal bids, depending on the interface; a complete proxy bid schedule is identical to a bid in a sealed-bid auction). At any price of the clock, the computer will automatically – in the name of the bidder – demand the respective quantity that is determined by the bidder’s proxy-bids.

During the course of the auction, bidders can update their proxy-bids insofar as the demand at the current or a future clock price is affected, i.e. a bidder can change his demand function for the current and all higher prices[38].

[38] An equivalent formulation would be that bidders can change their marginal bids for all prices at least as high as the current clock price.

Proxy-bidding does not impact the pricing or allocation rule. The formulae given above for the calculation of the closing price and the allocation of goods also hold in a clock auction with proxy-bidding.

Intra-round Bids

Intra-round bids are an enhancement in clock auctions with proxy bidding, but have not been tested in the experiment. Intra-round bids do not require additional technical functionality. The distinction whether intra-round bids are allowed or not, only affects the user interface. If intra-round bids are not allowed, demand functions can only be defined at feasible clock prices.

With intra-round bids, the user interface allows for a finer granularity. If, for example, a clock ticks in integer price steps ($1, $2, $3, …) and intra round bids are not allowed, bidders can specify their demand only at these prices. With intra-round bids, a bidder could, for example, also specify that her demand drops from 15 to 12 units at a price of $4.37.

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Appendix A

Extension of the Micro Rules

Extension of the Micro Rules

In this appendix, we extend the micro rules described in Chapter 6 to simultaneous auctions of two or more items. The explanation is based on the notation introduced in Chapter 6.3.

A.1 Sealed-bid multi-unit single-item auctions

Technically, clock and sealed-bid auctions are very similar. Both the price determination and the computation of the allocation can be performed by the algorithm of the clock auction described in Chapter 6.3. In a sealed bid auction, each bidder submits a non-increasing demand function.[39] The system then calculates the marginal bids as well as the aggregated demand function $D(p)$ as defined in Chapter 6.3, i.e.

$$D(p) = \sum_{i \in N} d_i(p) .$$

For pricing and the allocation of items, the formulae given in Chapter 6.3 for clock auctions also apply for sealed-bid auctions.

A.2 Simultaneous multi-item multi-unit auctions

We consider an auction in which m different items are auctioned. The set of items is denoted by

$$M = \{1, 2, \ldots, m\} .$$

Of each item $j \in M$, a real-valued quantity s^j (supply)[40] is being auctioned. The totally available quantities of all items are given by a vector

$$\bar{s} = (s^1, s^2, \ldots, s^m) .$$

The terms introduced in Chapter 6.3 are adapted to the case of two items by including the index j. In this notation, the bid schedule of a bidder $i \in N$ for item $j \in M$ is given by the set

$$B_i^j = \left\{ \left(p_{i,1}^j, q_{i,1}^j\right), \left(p_{i,2}^j, q_{i,2}^j\right), \ldots, \left(p_{i,l_i^j}^j, q_{i,l_i^j}^j\right) \right\} .$$

The demand of a bidder $i \in N$ for item $j \in M$ at a price p is denoted by $d_i^j(p)$ and refers to the *total* quantity the bidder intends to buy at this price.
The bidder's *demand function*, which maps any price p to his demand at this price, is given by

$$d_i^j(p) = \sum_{(p_{i,k}^j, q_{i,k}^j) \in B_i^j \,|\, p_{i,k}^j \geq p} q_{i,k}^j$$

A.2.1 Sealed-bid auctions

The extension of a single-item multi-unit sealed-bid auction to multi-item multi-unit applications is straight forward. Each bidder submits a non-increasing demand function (or a schedule of marginal bids) for each item $j \in M$. The auctions for the items are considered independently and each auction is evaluated individually. Thus, in terms of algorithms for the pricing and the allocation of goods, there is no difference to single-item multi-unit auctions.

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[39] If the user interface is based on marginal bids, the bidders' demand functions are calculated by the software.
[40] In the CPRS context the amount of available permits of a particular vintage.

A.2.2 Bid sorting with sealed-bid auctions

In the experiments, we applied a modified version of Holt et al.'s (2007, addendum) bid sorting algorithm. The revised version avoids not only price reversals, but also allocation reversals (see footnote 20). The modified algorithm works as follows: if an independent evaluation of the auctions would result in an inverted price structure, a fraction of the demand for the less valuable item is shifted to the more valuable item. The quantity of the shift is calculated such that the resulting auction prices of the two items are equal. Bidders who had bid for the less valuable item (i.e. the later vintage) will be awarded the more valuable item (i.e. the earlier vintage), in accordance to their proportional share of the shift. Fractions of the minimum contract size are resolved by a random approach or the Hare-Niemeyer rule.

A.2.3 Open clock auctions

In a multi-item extension of the clock auction, several items are auctioned simultaneously. Thus, there is a separate clock for each item. Bidding for all clocks proceeds in synchronized rounds. At the end of each round, the aggregate demand for each item is determined and all clocks at which aggregate demand is larger than supply tick to the next current price. Clocks at which the aggregate demand does not exceed supply keep their price for the next round.

The advantage of the simultaneous approach is that it allows bidders to shift demand from one vintage to another during the course of the auction. This gives bidders the flexibility to react to price differences and to adjust their demand accordingly. By this flexibility, the simultaneous format facilitates efficient outcomes.
Note, however, that switches of demand from one item to the other imply that a bidder increases his demand at this item. Thus, the activity rule needs to be refined: In a multi-item clock auction (suited for the case of auctioning emissions permits) the *total demand* of a bidder over all items is computed in each round. The activity rule requires that the total demand of a bidder may not increase from round to round.

As has been argued in Chapter 2.4.4, some more details have to be considered: The postulate of efficiency requires that for every vintage the following holds: if at any time during the auction (i.e. in at least one auction round) the demand for a vintage meets or exceeds the supply of this vintage, the supply of this vintage must completely be sold in the auction. Moreover, no bidder must receive more permits than the activity rule allows, i.e. her total demand at the closing price of the auction, either the last or penultimate prices.[41] As a consequence, demand switches have to be restricted in a certain way. Several solutions are possible. For the experiment we designed and implemented a rule that fulfills the above requirements. The rule is described in the following section.

[41] The latter is particularly crucial if bidders have a limited budget.

A.2.4 Ex post adjustment of demand switches

Consider two different vintages A and B with a supply of $s = (s^A, s^B)$. Let $D^A(p_t)$ and $D^B(p_t)$ denote the aggregate demand for A and for B in round t = 1, 2, … . From the second round on, bidders may switch (parts of) their demand from one vintage to the other, where $x_i(t)$ denotes bidder i's planned demand switch from A to B and $y_i(t)$ his planned demand switch from B to A in round t = 2,3… . Note that $x_i(t) > 0$ induces $y_i(t) = 0$ and vice versa. The planned aggregated demand switch from A to B over all bidders in round t is then given by $X(t) = \sum_{i \in N} x_i(t)$ and from B to A by $Y(t) = \sum_{i \in N} y_i(t)$, respectively.

In the first step of the ex-post adjustment rule, $X(t)$ and $Y(t)$ are offset against each other by calculating the planned net demand switch from A to B

$$Z^{AB}(t) = \max\{ 0, X(t) - Y(t) \}$$

as well as from B to A

$$Z^{BA}(t) = \max\{ 0, Y(t) - X(t) \}.$$

Note that $Z^{AB}(t) > 0$ induces $Z^{BA}(t) = 0$ and vice versa. In case of $X(t) = Y(t)$, which implies $Z^{AB}(t) = Z^{BA}(t) = 0$, the demand switches do not need to be ex-post adjusted. Only if one planned net switch amount is positive, an ex-post adjustment of the larger demand switch may become necessary. For the following, let us assume $Z^{AB}(t) > 0$, i.e. the planned total demand switch from A to B is larger than the planned switch in the opposite direction.

In the second step, the ex-post reduction amount $R^{AB}(t)$ for the planned switches from A to B has to be calculated:

$$R^{AB}(t) = \max\{ 0, \min\{ Z^{AB}(t), s^A - (D^A(t\text{-}1) - Z^{AB}(t)) \} \}$$

The reduction amount $R^{AB}(t)$ is given by the minimum of the net demand switch $Z^{AB}(t)$ and the (virtual) excess supply $s^A - (D^A(t\text{-}1) - Z^{AB}(t))$, which is caused by the planned net demand switch $Z^{AB}(t)$ from A to B. Only if $R^{AB}(t) > 0$, an ex-post adjustment of the planned demand switches becomes necessary. Note that in case of $s^A \geq D^A(t\text{-}1)$ the ex post reduction amount $R^{AB}(t)$ is equal to the planned net demand switch $Z^{AB}(t)$. That is, if an excess supply of A already existed in the previous round t-1, the total demand for A is not allowed to be reduced by demand switches from A to B in round t.

In the last step, if $R^{AB}(t) > 0$, the individual demand switches have to be ex-post adjusted by proportional reductions of bidders' planned demand switches. That is, instead of her/his planned switch $x_i(t)$, bidder i's demand switch from A to B is ex-post reduced to

$$x_i^r(t) = x_i(t) \cdot (1 - R^{AB}(t)/X(t)).$$

Hence, the adjusted total demand switch $X^r(t)$ from A to B is given by

$$X^r(t) = \Sigma_i x_i^r(t) = X(t) - R^{AB}(t),$$

i.e. the planned total demand switch $X(t)$ is ex post reduced by $R^{AB}(t)$.

In the example above, $X(t) = x_i(t) = 10$ and $Y(t) = 0$, which leads to $Z^{AB}(t) = 10$ and $Z^{BA}(t) = 0$. Applying the ex-post adjustment rule, we get

$$R^{AB}(t) = \max\{ 0, \min\{ 10, 100 - (105 - 10)) \} \} = 5.$$

That is, the aggregated planned demand switch from A to B has to be ex-post reduced by 5 units. Since only bidder i intends to shift demand from A to B, it is only his planned switch which is reduced by the adjustment, i.e.

$$x_i^r(t) = 10 \cdot (1 - 5/10) = 5.$$

That is, bidder i's planned demand switch of 10 units is ex-post reduced to 5 units. Therefore, the actual aggregated demand for A in round t is equal to the supply of this vintage, i.e. $D^A(t) = s^A = 100$. If the auction ends with this constellation, bidder i receives 10 units of A at the price $p^A(t)$ and 5 units of B if, as before, the total demand for B is assumed to be completely fulfilled. Hence, bidder i receives exactly the number of allowances he demanded at the selling prices, namely 15 units.

Note that the necessity for ex-post adjustments of demand switches has to be checked before pure demand reductions for the vintages are considered. Let us illustrate this by extending the example above. As before, in round t, bidder i intends to shift 10 units of his demand from A to B. Moreover, assume that he additionally intends to reduce his demand for A to zero units. Thus, in round t, bidder i plans to demand 10 units of B only. We now notionally separate between demand shift and pure demand reduction and firstly take demand switches into account. Then, without considering bidder i's demand reduction for A, the situation is same as in the example above. Therefore, the ex-post adjustment of bidder i's demand switch has to be the same too, i.e. instead of shifting $x_i(t) = 10$, he is only allowed to shift $x_i^r(t) = 5$ units from A to B. By additionally taking his demand reduction of 5 units into account, bidder i then demands 5 units of A and 5 units of B. As a consequence, the aggregate demand for A in round t yields $D^A(t) = 95 < s^A = 100$. Thus, if the auction ends with this constellation, the excess supply of 5 units of A in round t has to be proportionally allocated to the bidders (with respect to their demand reduction for A in round t) who have generated the excess supply. Since only bidder i reduces his demand for A, the total excess demand has to be allocated to him. That is, he receives, as before, 10 units of A but now at the price $p^A(t-1)$, because this was the last round in which the demand for A meets or exceeds the supply of this vintage.

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