Using Theory, Markets and Experimental Methods to Improve a Complex Administrative Decision Process: School Transportation for Disadvantaged Students

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Abstract

The paper studies structural inefficiencies of administrative decisions demonstrated in an example from the growing government service sector. The provision of school transportation to disadvantaged children touches social concerns and regulations related to classical conditions of limited competition. The decision process is partitioned into key economic functions related to the challenges faced by the government when dealing with environments in which theory predicts market failures. Theories drawn from public choice theory and theories of auctions suggest policy changes that were experimentally tested in the challenging environment. Field data demonstrate the new processes produced improved allocations. Subsequent laboratory tests demonstrate the success can be attributed to the principles used in the theory and demonstrate a robust link connecting efficient behaviors observed in laboratory experiments and behaviors found in field events.

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1 The financial support of The Rising Tide Foundation and The John Templeton Foundation are gratefully acknowledged. The tireless efforts of governmental and educational personnel who enthusiastically supplied their vast knowledge of institutional details of the problems faced by children, families, and institutions dedicated to improving the lives of disadvantaged students must be acknowledged and admired. Special acknowledgement is extended to Han Seo for his contribution to the route logistics model. The technical support of the Caltech Laboratory for Experimental Economics and Political Science made the project possible as was the assistance of Jacqueline Lodman. The auction implementation team consisting of David Brooks, Veronika Nemes and Amy Corman from the University of Melbourne are acknowledged for their assistance in preparing for and hosting the auction event.
1. Introduction
This paper explores, expands and applies a methodology for implementing market-based replacements of administrative processes used for the provision of governmental services. Governmental services provision is one of the largest and fastest growing sectors of governments and it is also one of the most challenging. The allocation issues often span multiple economic environments that theory suggests are incompatible with decentralized, market-based allocation processes. With neither theoretical guidance nor examples of market successes, policy makers implement administrative processes. Consensus often holds that administrative processes are inefficient, but no one seems to know how to fix the problems. This paper explores the issue with a focus on a specific case and asks if and how it can be done.

The paper reflects a non-traditional approach in which the study of a complex administrative process reveals that there is no implementable, encompassing, decentralized, efficient alternative. The existing administrative process is examined in detail and decomposed into components where key economically relevant decisions take place. The components are then examined for features that might support separate market-based processes. The examination is structured around natural questions: what are the inefficiencies or problems that emerge from the exiting administrative procedure; which components of the problems can markets be crafted to solve and which cannot; and how can components be recombined into an allocation process? Each component confronts an economic environment traditional theories hold will lead to market failure. The environments include public goods with the associated possibility of free riding, non-convexities with the associated possibility of non-existence, multiple equilibria with coordination challenges and thin markets with the associated possibility of collusion. The paper focuses on each of the components to create conditions that might support market-based processes designed to avoid the failure suggested by theory.

The new processes are designed, studied experimentally, and then implemented in the field. The data from the field implementation are compared to the results of the original administrative process. The implemented policies produce results superior to the results of the
original, administrative process. The study then explores the reliability of the model as the data collection is moved between laboratory and field conditions. Measurement taken from the field are implemented under laboratory conditions and thus laboratory experimental methods combined with field techniques are used as tests of robustness of background models. The principles at the foundation of the economic models are supported in all tests and are thus supported by both sets of data. The possible lack of correspondence between laboratory results and field data are often found in methodological discussion of “external validity” and “internal validity”. Cases in which the correspondence might fail are documented by Harrison and List (2004). The robustness approach used here avoids some of the philosophical issues.

While the focus is on one example, getting disadvantaged children to school and back home, the example stands as an exemplar of a class of cases in which key allocation decisions are made through administrative processes in a large institutional setting. The economic and the implementation problems are broad challenges to market-based policies. Thus, a detailed study of the special case is more than a simple example. It demonstrates a possible methodology and strategy for determining how appropriate markets might be designed, implemented and evaluated as administrative process replacements that help the governmental services recipients and governments.

Final evaluation and assessments of the overall policy design and implementation are organized through three experimental testbed questions developed by Plott (1994):

(i) *proof of principle* - did the system do what it was designed to do;
(ii) *design consistency* - did it do it for understandable reasons—the principles used in the design—as opposed to a lucky accident; and
(iii) *robustness* - is the real-world evidence “robust” in the sense that the results produced by the system are consistent with slight variations in field and experimental environments?

These questions differ from typical analysis related to theory testing exercises. The first reflects the goal orientation of the design and the second reflects the role of underlying science. The third reflects the generality of the underlying theory and the field environment in which neither
full control nor complete observations exist. It deals with the reliability and robustness of theory as the application is changed from laboratory experimental conditions to naturally occurring applications and to implementation - from one environment to another where possibly unobserved differences exist. The issues are sometimes discussed as problems of external and internal validity.

2. The Background Policy Challenge
While the study is an economic policy relevant to real people with real problems the perspective is on the underlying economic principles that drive the results. The public service to be studied is transportation for children with autism to and from a specialized school. The school itself is held in high regard attracting students from a large geographic region. The rationale for a coordinated transport service for students to and from school is obvious but there are many complexities that impede the efficiency and effectiveness of such services. Consensus among administrators, the schools’ faculty and student’s parents hold that the current system of transportation is poorly optimized. It is fully subsidized\(^2\) but the service provided does not meet the “client focus” criteria established as a core objective of the sponsoring policy. The current transportation system takes significant time out of the children’s day. Each day, the children, who require supervision, spend up to four hours a day riding a large bus to and from school (two hours each way), arriving late at school and at home. The long bus ride tires the children, and they are required to catch a connecting service that can be a source of additional frustrations. The cost is time that could otherwise be devoted to classes and family. It is no surprise that parents often claim that their most difficult and challenging task is getting the children to school and back. Many are single parents with multiple children and constraining job schedules. A comment often heard is: “Nothing goes right”. A wide consensus holds that a transportation problem exists, but improvements are difficult.

\(^2\) The subsidy is through the Australian National Disabilities Insurance Scheme (NDIS). Travel services are funded on an in-kind basis under the NDIS but are procured through the Students with Disabilities Transport Program managed by the Victorian Department of Education and Training (DET).
Transport services are provided by private operators through service contracts that are allocated by the responsible government agency. A standard government procurement framework including pre-qualification, sealed-bid tender followed by bilateral negotiation is used to allocate and price transport service contracts. This standard process is essentially a “beauty contest” resulting in open contract terms. Because the information is asymmetric, the bus company has information about costs, possible routes and times that are not available to the school procurement process. Because there is no obvious allocation mechanism, negotiation is time-consuming. This allocation process relies on a winning firm to design the transport service offered to students and is, effectively, an administrative and informal way of addressing the network externalities and other transaction complexities that cannot not be resolved through standardized public sector procurement process.

A key insight is that the delegation of route design and vehicle specification decisions to bus operators has resulted in the emergence of transport services that reflect the profit incentives implicit in the underlying scale economies at the expense of service quality. Thus, a form of a principle-agent issue seems to have emerged in which the decision-making agents’ preferences (the bus companies) are not closely aligned with those of the principle and the principle has limited information.

Superficially, properly specified regulations with clearly specified quality constraints might appear to be a solution. However, asymmetric information between the service provider and the policy administrators creates difficulties. An information gap also exists between the preferences of the parents, who are the intended beneficiaries of the service and the regulators. Even if the regulators are endowed with information about the preferences that might be implemented, the regulators do not have adequate information due to limitations imposed by costs or the realities of network complexity. On the other hand, those that know costs and can influence the costs do not know the preferences or have limited incentives to implement them if they did know them. On the surface it might appear to be an unresponsive
bureaucratic process but at the base is an asymmetric information and institutional design problem.

3. Project Overview, Design Objectives and Development
The project methodology was motivated by a design and experimental testbed approach to policy. The overall goal was to improve the service without significantly increasing cost. Service improvement was interpreted as implementing a “customer” orientation where the customers are the parents and the school. Different dimensions of service were considered as influenced by different governments responsible for the use of public funds or public safety, especially where children and educational institutions are involved. The overlapping responsibilities and authorities created organizational conflict that necessitated the support of upper levels of government. This key support of upper levels of government provided access to officials and an understanding that procedures and policies could be modified if needed. It is important to recognize that we found no “governmental utility function” that might be optimized.

Although broadly understood as a transport problem, busses (in contrast with trains or trams) are a relatively unconstrained form of transport network. The advantage of busses is flexibility because routes can be assembled from segments of the existing road network, rather than fixed rail infrastructure. However, other considerations including: the number and location of students; safety and supervision requirements; budget limits; reasonable travel times, and other non-negotiable policy constraints will influence the bus network provided.
Economic theory suggests why this allocation environment contains many features that can cause market failure at both theoretical and practical levels. For example, the pickup locations have the properties of public goods, both in regard to location and timing of pickups. Conflicts that exist among the “customers” creates a “preference aggregation” problem with theoretical and “impossibility” issues well known in the social choice literature. The classical competitive model for price determination is challenged by economies of scale related to vehicle capacities and the zero marginal cost caused by excess vehicle capacity (partial fills) due to problem causing non-convexities. Thus, equilibrium of classical models need not exist. Other non-
convexities related to individual route configuration, multiple possible routes and the need for coordination, competition with multiple possible equilibria, challenge equilibrium existence or uniqueness. Transportation cost reduction is also challenged by possible collusion among bus operators organized through a bus company association.

These complexities suggest that there is no obvious, implementable, decentralized allocation mechanism that solves all of the problems. A reductionist methodology was used to explore and develop possible process improvements applied in sequence. For this approach, the problem was deconstructed into three components: service quality preference (discussed in Section 4), route design (Section 5) and route allocation (Section 6). The outcomes from the alternative allocation process, behavior and dynamics are discussed in Section 7. Section 8 examines the success of the underlying science by assessing deeper and methodological question posed in Section 1. It examines outcomes achieved in the field in terms of proof of concept, design consistency and robustness. We examine whether the policy mechanism developed performed according to the basic economic principles used to guide the design. We also focus on the relationship between laboratory experiments and “naturally occurring” behaviors as encountered in field work as an evaluation technique. A new technique is developed in Section 9 and is applied to resolve the issue of robustness. Section 10 is a summary of conclusions.

4. Service Quality Preferences
The first step following the establishment of high-level support was to formulate and define services to be delivered. Services took multiple forms with complex attributes with different implications for market-based provision processes. Some quality attributes such as: vehicle safety, working with children accreditation and supervision requirements are mandated by the State. Supervision is provided by a professional chaperone whose task is to attend to students’ needs and maintain a safe and secure environment, particularly for younger students and those with severe disability. These supervision requirements can only be achieved with vehicles that have a center aisle, but this eliminates smaller vehicles (below 20 seats) from consideration in
route design. Other transport service qualities relating to maximum travel time, timely arrival at school and student collection stations were developed from discussions among school administrators, teachers, and parents. A maximum travel time of no more than one hour (each way) was defined for any student using the bus service. Timely arrival of the bus service prior to the start of the school day was also identified as a required service quality attribute since late arrival of the bus service imposes a negative externality on all students and teachers attending the Northern School for Autism. A third service quality defined the locations where students would be collected and returned each school day. Considerations such as: parking space and access for parents, safety, shelter and proximity are taken into account by school administrators.

The service qualities determination is a social choice problem of choosing the public goods (the service qualities) supply to a population of parents and teachers among which service quality preferences differed. The complex problem of determining public goods supply was largely facilitated through the Public Choice mechanisms of multiple, small group meetings and consultations with parents organized and structured by school administrators.\(^3\) The quality of service with respect to pick-up/drop-off locations, safety, duration of journey, removing the second leg and timely arrival at school were the primary motivation to reform the previous service. Cost was also an issue, but it was considered to be of second order.

5. Route Design

Route design is the second component of the proposed allocation process. Seventy-nine of the children attending the senior campus of the Northern School for Autism participated. These students attend school two hundred days a year. As noted earlier, the previous allocation process delegated route design to bus operators. The routes established under this system had children picked up at predesignated collecting areas and transported to a central hub (the junior campus) where they would then change buses before finally being transported to the

\(^3\) Details of the meetings are not documented. Impressions from discussion with the school administrator suggests that no formal voting rule was in place, but one participant had veto power (the school administrator).
senior campus. The second leg of the bus journey led to the late arrival of travelling students at the senior campus (by around 30 minutes), but also disrupted class for other students.

Each child was assigned to a pickup location. The parents had the responsibility of transporting their child to the pickup location at the scheduled time, so parents had preferences about locations. This assignment was a public goods decision problem, the solution of which was determined by a school/parent decision process. The determination of pickup locations included issues of safety, parking and shelter, and eventually resulted in 35 pickup locations, with one to seven individuals picked up per location. Data from the previous service and experience with school transportation suggested that a stop to pick up children required about 90 seconds per child at the stop. The logistics challenge was to determine the number of buses and the route of each bus needed to transport all students to and from school given the service quality attributes required. In this context, a route is defined by a sequence of pickup stations. Service quality requirements were implemented through: i) prequalification (e.g., safety, supervision, seating configuration, accreditation of drivers and chaperones); ii) pre-determined (e.g., pickup stations and single leg service); and iii) constraints on the route formation methodology (e.g., the one-hour maximum travel time, timely arrival and bus size). Factors such as: traffic congestion, traffic light patterns, bus access to city streets and overhead clearance, traffic management arrangements, on-bus disruptions etc. had to be considered in the route design process.

Technically, two large buses could be used to transport the 79 children, but that option was not feasible because of the one-hour maximum ride time, as the estimated time to stop for 40 children would be more than the maximum ride time. The policy that the minimum size bus would have a capacity of 20 (due to supervision requirements) and available supply of bus sizes dictated that all buses would be the same size. From an economic point of view, the route

4 Exactly how this public choice process worked was not investigated. Available reports suggest that the school administration met with small groups of parents and was vested with considerable authority of veto powers with parents having direct input and voting. Accepted models and experiments suggest that the administrator’s most preferred alternative would be in the core of the small group decisions.
determination objective became minimizing the number of buses used subject to the constraint that all children were picked up and no child was on the bus for over an hour. Other criteria such as minimizing the average time students were on the bus were considered, but after discussions with administrators, the other criteria were not used. The distance between each of the 1190 pairs of pickup locations was determined using street maps and verified by Google Maps. Driving times between the pairs of pickup locations were based on traffic flow models for the area and sampled though Google Maps. The data from the 1190 pairs of pickup locations were used to compute candidate routes that would have all children picked up, with 90 seconds per child allowed for loading and unloading at a pickup location. The fact that excess capacity would exist on the bus and the small number of children at each pickup location (typically one to three with only six stops with four or more and one with seven) suggested an efficiency-based assumption that no more than one bus would visit a drop-off location.

The collection of assumptions resulted in an estimate that seven buses would be used and thus seven routes needed to be determined. A constrained optimization was performed to partition pickup locations into seven routes subject to the constraints that no route took longer than an hour. The routes were not unique but were further refined such that the pick-up was consistent with the direction the vehicle was traveling. Even with constraints, hundreds of thousands of possibilities existed. Google Maps sampled at different times of day was used to estimate the time a route would take during the time that the bus would be operating. The routes were then driven by members of the research team to check route feasibility with respect to traffic flow, road conditions, obstructions and other practical issues. Those calculations resulted in seven routes, characterized in terms of the locations of pickups and the children to be picked up at each, that defined the bus services to be procured.

The routes are illustrated in Figure 1. The economic modeling work predicted that no child would be on the bus more than an hour. The previous routes that the school had used in the past are illustrated in Figure 2. As previously mentioned, the former routes were based on a hub and spoke design that had students transported to a location where they changed buses.
The old transportation system illustrates the tradeoff between a reduced cost to the bus company and an increased cost to families in terms of the time on the bus.

Once created by the research team, the routes were verified by the school and by companies that would sell the needed transportation services. Once defined, each route could not be changed by the bus company hired to provide services. The decomposition of the procurement from a single supplier of all routes to a competitive procurement of multiple routes and multiple suppliers (discussed in Section 6) was a major departure from historically used procurement procedures.

A daily log maintained by the drivers allows for a comparison between the model predictions and the actual travel time. The comparisons are contained in Section 7. One model error was due to a mistaken address. A measurement error was due to a congested intersection that was subsequently avoided by the driver.

Figure 1: Analytically Determined Routes Used in the Auction

Figure 2: Previously Used (the old) Routes
6. Route Allocation - Auction Design

The seven routes identified above, were allocated to private transport operators through a new form of (computerized) auction. The auction was designed as a decreasing price, continuous, simultaneous, multiple item auction. The theoretical model for the auction is based on the best response, competitive model. Bidders select items and place bids in real time. Whether or not the bid becomes a leader on the item or if a bid was replaced as leader was quickly apparent during the auction. A countdown clock reset with any new leader in any market. The auction ended and all markets closed if the countdown clock reached zero. The performance success of the continuous multiple item auction is well established in field applications for scale (Plott, 1997) and complex variations (Plott, Lee and Maron, AER 2014). The basic theoretical properties are analogous to multiple items, ascending price auctions see Demange, Gale, and Sotomayor (1986) or for models based on discrete rounds see Milgram (2000) or Plott and Salmon (2004). For analysis of multiple unit auctions see Kwasnica and Sherstyuk (2013).

The school routes auction is a new form of auction that had important, untested features. Furthermore, the auction was to be applied to environments that had never been studied. Probity restrictions-imposed auction features that are new to the auction literature. Thus, the application required a testbed phase. The prominent and special features included:

(i) **Starting prices and decrements** - The auction was a decreasing price auction, reflecting the fact that the auction was a procurement as opposed to a sale.\(^5\) The decreasing price feature implied the need for starting prices (the maximum price that a bidder could offer on an item) and a decrement requirement defining the minimum difference between a current leading bid and a new bid.

(ii) **Thin market** – A combination of factors including onerous prequalification, short-term contracts\(^6\), a tight procurement schedule and opposition to a competitive allocation

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\(^5\) Decreasing price auctions are typically considered as following the same principles (inverted) as increasing price auctions. For comparisons in a clock auction context see Deck, Servatka and Tucker (2019).

\(^6\) The standard contract term is 10 years, but a three-year contract was offered in this instance to synchronize with other bus contracts.
process by the bus industry led to only three bidders in the auction. The thin market feature raised an obvious possibility of collusion.

(iii) **Probity imposed substantive interventions** - Although the auction was designed specifically to address complexities relevant to the allocation problem, it deviated significantly from the standard procurement process. This created a range of procedural and probity issues that had to be resolved. The open auction format (needed to accommodate common values for combinations of routes) was argued by probity to contravene the standard government procurement practice in which a sealed bid is lodged by each bidder, is confidential and cannot be revised. A considerable investment was also made to justify and demonstrate the advantage of the proposed auction format in which participants can revise their bids (down) in light of the combination of routes in each bidders’ portfolio and the bids placed by others. A second probity requirement restricted bidders’ participation to only those routes identified in their “expression of interest” used as part of the state’s traditional procurement bidder screening process. Two bidders expressed interest in all seven routes, but one bidder identified interest in only three routes. Last minute changes to auction software were needed to implement this requirement so that no bidder was aware of possible constraints on any other bidder. Other standard procurement procedures were implemented and the probity official was assigned special powers in the auction.

**6.1 Bids, Starting Prices and Decrements**

The role of the auction was to allocate commercial contracts for each defined route to private bus operators. Bids in the auction were defined in terms of the daily payment needed to collect students from each pickup station, provide on-route supervision, deliver students to school and return them at the end of each school day. As indicated above, three-year contracts were offered in which there are 200 school days per year. The starting bid was set substantially above previous contract prices and prices for bus hire available online. This information provided a crude and inaccurate guess about final auction prices, and thus how far prices would fall during the auction. A standardized decrement was set based on estimates about the
number of bids that would be tendered, guesses about bidding speed, the financial impact of the decrement, and the impact of alternative decrement values on how long the auction would last. The resulting decrement chosen was AU$25. As it turns out, all these guesses were substantially wrong, which provides some insight about the lack of information available at the auction design stage of the project. The final prices were lower than expected and the speed of bidding was faster. Starting prices were set at AU$1550 per day per route and the decrement requirement was AU$25. Therefore, the starting value of a contract was AU$930,000 (200 days per year x 3-year contracts x AU$1550 starting price) and the decrement value was AU$15,000 (AU$25 x 600).

6.2. Testbeds and Auction Preparation
Prior to the auction, the timing of governmental decisions prevented any extensive use and testing of the underlying theory. That said, a long history of experimental auctions provided important insights and expectations regarding auction performance and limitations. Tests were primarily limited to software and instructions testing. However, the methods created for testbed experiments proved useful for the more developed tests that will be addressed in Sections 7 and 8, where the auction performance is discussed.

The multiple items, simultaneous, declining bids auction (as opposed to ascending) have not been studied in the literature. New experimental procedures were needed to deal with the reversed direction on the auction. Subjects in testbeds were allowed to sell “services” with value created by opportunity costs imposed in the form of clearly stated “outside offers”. A bidder allowed to provide a service (e.g., transportation on a route) could sell the service in the auction or sell to the outside offer provided by the experimenter. When the price fell to near the outside offer, a strategically behaving, optimizing agent would stop bidding to sell in the auction and sell at the outside offer instead. The price at which the bidder stopped bidding is called the “dropout price”. The situation is analogous to the induced preference method typically used in seller experiments, in which sellers in the auction must buy the item from the experimenter at a predetermined cost before agreeing to sell the item in an ascending price
auction with competing buyers. The cost plays the role of minimum price at which the seller would accept in an ascending price auction, analogous to how opportunity provided by the outside offer dictates the minimum price that the bidder would sell in the descending price auction. The difference is that in the typical seller experiments the seller is exposed to an out-of-pocket loss if the selling price is below the cost while in an auction with an outside offer, the opportunity cost, an out-of-pocket loss is not possible.

Other government policy issues created uncertainties in the design and test-bed phase of the auction. The special probity rules noted above (Section 6 (iii)) had not been studied and neither the exact number of bidders nor the exact rules dictated by probity were known until just a few days before the auction. Probity issues also prevented the auction team discussions with potential bidders, so such sources of information were not available. Thus, direct information about possible cost or expectations were unavailable. Testbed parameters were estimates of bus company cost inferred from bus prices posted on the web together with the estimated times and distances in route models derived from theory. Therefore, numbers could be off by orders of magnitude. In this design environment, given the timing of probity decisions and the official date of the auction set by the regulators, only two experimental sessions consisting of three experiments were possible and these experimental sessions were dedicated to the study of the two bidding conditions that might be imposed on the auction by probity. The probity decision would be made at a date too late to do additional tests. One experimental configuration restricted the bidder to winning no more than three routes and the second configuration restricted the bidder to bidding on only three specific routes.

Experimental parameters based on cost estimates were presented to subjects in the form of opportunity costs (See Table 1). The financial units are in terms of an artificial currency called francs, worth $0.0015/franc. Testbed bidders were told that they had seven items to sell and the money received was the subject’s to keep. The subjects could either sell at the auction with winning bids or sell to a private offer, where the private offer represented the subject’s
opportunity cost in supplying the item. Private offers were listed in each subject’s incentive sheet which was given to them before the start of the auction.

<table>
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Table 2 contains predictions conditioned on theory for both types of bidder constraints, constraint 1 and constraint 2, considered by the government. Under constraint 1, bidder 311 could win no more than three items, and under constraint 2, bidder 311 could bid only on items 2, 3 and 6. Bidders could view only their own bids, the minimum required to place a bid, and the current leading bid (but not who placed it). Restrictions on bidders were unknown except to the restricted bidder and the number of other bidders was unknown to a bidder. Of the three testbed experiments that were conducted, one experiment implemented “constraint 1” and two experiments implemented “constraint 2”.

Each bidder knows own cost with certainty. When placing a bid on a route the bidder knows with certainty the bid amount needed for it to become a “leading bid” and thus a winning bid should the auction end. In the absence of additional information, a natural model of behavior is as a “best response”. Set the bid equal to the existing (leading) bid minus the decrement requirement if the resulting bid is above the bidder’s cost; previous bid minus bid equals minimal decrement. Table 2 lists the theoretical prediction for the price of each route and the experimental outcomes for the testbed exercises. The theory holds that the bidder with lowest cost wins and pays a price approximately equal to the cost of the second lowest cost bidder minus the decrement requirement. In these testbeds the decrement was only 1f. Experience
suggests that experimental subjects will not trade for zero and will require a small profit in order to trade, so for the testbeds the predicted change in price due to bids is not precise.

| Table 2. Testbed Experiments: Theory and Experimental Results experiment 20181125. |
|---------------------------------|---------------------------------|---------------------------------|----------------------------------|-----------------------------------|
| Testbed 1 constraint 1 311 cannot win more than three items | Testbed 2 and 3 constraint 2 311 can bid on only routes 2,3,6 | item | theory | result1 | item | theory | Result 2 | Result 3 |
| 1 | 1247 | 1228 | 1 | 1327 | 1325 | 1311 |
| 2 | 1085 | 1150 | 2 | 1085 | 1075 | 1100 |
| 3 | 1244 | 1229 | 3 | 1244 | 1175 | 1176 |
| 4 | 1013 | 1019 | 4 | 1260 | 1275 | 1222 |
| 5 | 922 | 956 | 5 | 1072 | 1050 | 1094 |
| 6 | 1061 | 1054 | 6 | 1061 | 1050 | 975 |
| 7 | 1029 | 1023 | 7 | 1029 | 950 | 1022 |

The numbers were to be compared to theory and were not considered as any form of prediction about the upcoming auction, given that the field parameters were unknown. The pooled results of the pilot experiments are statistically indistinguishable from theory, suggesting theory reliability. While testbed results were sufficiently close to theory to prevent alarm about the basic principles, the parameters that might exist in the field were still totally unknown. Opportunity costs, bidding speed and variance could be sources of problems. Furthermore, the possible behavior of the bidders due to their business orientation and training, the effects of monetary magnitudes and the propensity for collusion were also unknown. The behavior of the experimental subjects seemed consistent with theory and their behavior indicated no recognition of the possibilities for collusion by the bidders. In spite of all of the unknowns, the key feature of dominant strategy seemed to work.

7. The Auction

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7 A regression of the experimental results on the theoretical predictions produces an intercept that is not significantly different from zero and a coefficient on the result of 0.96, standard error of 0.0074, t statistic of 13 and P-value of 6.32 E-11, when expressed as an indicator of closeness of fit.
The auction was conducted in the Experimental Economics Laboratory at the University of Melbourne, Australia with auction software that was housed in California on a Caltech computer connected to the internet. Programs, internet speed, web interface and machine compatibilities were proofed and tested several days in advance. All computer interfaces were inspected by the probity officer for policy compatibility. Only the probity officer and the Caltech team viewed the auction and the real time flow of bids.

The bids submitted by the transportation companies competing for routes were tendered by a team of two or three company employees. While the identity of participants was strictly confidential before, during and after the auction, nevertheless, it is possible that bidders knew their competitors through informal channels. A range of measures were taken to maintain experimental standards and bidder confidentiality. Separate information and practice sessions were held for each bidding company by a separate member of the auction team referenced as an auction “coach”; on auction day, participants arrived at separate, predesignated times and were escorted to a room where they met their coach; bidders were allocated separate, private bidding rooms; and coaches prevented individuals from using cell phones or wandering around the facility, where they might see or learn the number of or learn the identity of other teams. When the auction ended, separate administrators went to bidder rooms to verify the sale and sign agreements. Bidders left the auction at separate times with no information about prices received by other bidders or other bidder identities. Bidders were asked about the number of bidders and all suggested that the number was in the range of five to eight, thus the thin market was not detectable.

7.1 Auction Outcome
The final auction prices of routes and the auction winners are listed in Table 3. Bus transportation on all routes was procured. One seller (ID 322) won five of the seven routes (approx. 70%). Another seller (ID 321) won two of the routes (approx. 30%) and the constrained seller (ID 323) participated aggressively but won none (0%). Prices were in terms of AU$ payments per day for 200 days per year for three years.
Table 3: Final Auction Prices (mean 684.8).

<table>
<thead>
<tr>
<th>Route</th>
<th>Auction final (winning) price (AU$/day)</th>
<th>winning Seller ID</th>
<th>Last dropout price (second to last bid) (AU$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>617</td>
<td>322</td>
<td>656</td>
</tr>
<tr>
<td>2</td>
<td>670</td>
<td>322</td>
<td>695</td>
</tr>
<tr>
<td>3</td>
<td>725</td>
<td>322</td>
<td>750</td>
</tr>
<tr>
<td>4</td>
<td>716</td>
<td>322</td>
<td>741</td>
</tr>
<tr>
<td>5</td>
<td>600</td>
<td>321</td>
<td>625</td>
</tr>
<tr>
<td>6</td>
<td>651</td>
<td>321</td>
<td>725</td>
</tr>
<tr>
<td>7</td>
<td>815</td>
<td>322</td>
<td>840</td>
</tr>
</tbody>
</table>

7.2 Auction Behavior and Dynamics

The auction lasted just under 15 minutes with 231 bids submitted, an average speed of one bid every four seconds. The final bid prices, the dropout bids for all routes and all sellers, are in Table 4. Dropout prices should not be confused with the prices a route commanded in the auction. The dropout prices of a bidder are the final bids on routes submitted by a bidder and are thus the lowest price the seller revealed as acceptable, interpreted as a seller’s revealed opportunity cost for the route. Approximations of dropout prices are used in the post auction analysis of Section 6 to calibrate the pattern of implied equilibria. Theory used to fashion the auction design predicts the actual seller of transportation service in the route will be the bidder with the lowest opportunity cost, and the sale price will be the dropout value of the bidder that has the next to lowest opportunity cost value (minus the decrement requirement). Note that the lowest acceptable value of the winning bidder will be below the winning bid. For the winning bidder, the lowest acceptable value is not revealed.
<table>
<thead>
<tr>
<th>Route</th>
<th>ID 321</th>
<th>ID 322</th>
<th>ID 323</th>
<th>Final (winning) prices (mean 684, sd 73.8)</th>
<th>Winning seller ID: the unknown minimum value is below final bid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>656</td>
<td>617</td>
<td>1335</td>
<td>617</td>
<td>322</td>
</tr>
<tr>
<td>2</td>
<td>695</td>
<td>670</td>
<td>745</td>
<td>670</td>
<td>322</td>
</tr>
<tr>
<td>3</td>
<td>900</td>
<td>725</td>
<td>750</td>
<td>725</td>
<td>322</td>
</tr>
<tr>
<td>4</td>
<td>741</td>
<td>716</td>
<td>1260</td>
<td>716</td>
<td>322</td>
</tr>
<tr>
<td>5</td>
<td>600</td>
<td>625</td>
<td>1310</td>
<td>600</td>
<td>321</td>
</tr>
<tr>
<td>6</td>
<td>651</td>
<td>725</td>
<td>800</td>
<td>651</td>
<td>321</td>
</tr>
<tr>
<td>7</td>
<td>840</td>
<td>815</td>
<td>1285</td>
<td>815</td>
<td>322</td>
</tr>
</tbody>
</table>

Figure 3 illustrates the time series of price decisions. The dynamic structure of price formation appears to be a series of price wars between a pair (the same pair, 321 and 322) of bidders that continue bidding the price of a route down until one of the two drops out. During these wars, bidder 323, the constrained bidder, is the leading bidder on the three routes the bidder was able to (and constrained to) bid on. This bidder was unable to participate in the “price wars”. The warring pair, bidders 321 and 322, continue to focus on a particular route until one of them drops out and starts bidding on a different route. If the new bid is on one of the three items 323 can bid on, then 323 responds. Prices decrease until 321 or 322 shift attention to a different, higher priced route where another price war begins. Prices on the three routes 323 can bid on, move at a similar rate of descent while prices remain high on other routes. In brief, the high-priced routes attract bids from 321 and 322, (possibly 323 if it is a route the bidder can bid on), starting a new bidding war, which continues until all, but one bidder drops out, then the process starts again on a new route.
No evidence exists of collusion or the strategic bid reduction that might be expected in such thin markets. Experiments have shown that colluding bidders typically recognize the fragility of collusive arrangements and do not return to the market after having stopped bidding in a seemingly collusive agreement (Li and Plott (2005) and Brown, Plott and Sullivan (2009)). Thereon, the pattern of repeatedly returning to a market to compete in the routes procurement auction suggests an absence of collusion. The time lag between a bid and a responding bid (four seconds on average) is very short. The absence of any form of collusive pattern suggests that the lack of information about the number of bidders, bidder identities or bidding patterns of any other bidder is a possibly effective design tool for thin markets. Bidders in the route auction have no information on which to condition collusion enforcing actions.
8. Policy Assessment (Proof of Concept): Did it do what it was supposed to do?

The assessments turn on questions posed in Section 1. The first, Proof of Concept, is: Did the auction do what it was supposed to do? There are essentially three measures used to assess the results for policy objectives. The first is the time required in the auction compared to the experiences with the government’s sealed bids process. The second is related to cost and efficiency. The third is the quality of the services provided as measure by the time that the children are on the bus.

8.1 Auction and Administrative Process Time

The difference in execution (as opposed to set up) time required for the conduct of the previously used, sealed bid process as compared to the continuously decreasing price auction is dramatic. The route auction lasted just under 15 minutes with more than 200 bids submitted, on average one every four seconds. By contrast, the time consuming, previously used sealed bid process consisted of a process of bid submissions followed by months of negotiations after winners were selected. The route detail was the substance of subsequent negotiations between the government and the auction winner. The combinations of these processes used in the past were reported to be major time-consuming factors, that were avoided with the continuous, decreasing bid auction used in the route auction. The improved speed of the route auction could be attributed to the crafting and auction of well defined, individual routes as opposed to a packaging of all routes for sale to a single seller of transportation services with major features left to a negotiation process.

8.2 Relative Cost: Auction Outcome and Previous Contracts

A comparison between the cost of transport services from the auction and a sample of existing commercial contracts for similar transport services is possible. Eleven existing contracts were sampled from information available on a government website. The auction outcomes were

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8 The times devoted to background activities times required for the auction are not included in the measures, i.e., meeting times for obtaining agreement on services, software development, route determination, testing, etc. Similarly, time required by the background activities devoted to the administrative process are not included.
then standardized to account for the duration of the different contracts, four years, two hundred days per year for the existing commercial contracts vs. three years, 200 days per year for the route auction contracts.

The auction achieved at least equivalent contract rates compared with the sample of contracts allocated by the previous procurement method. As mentioned previously, Table 4 contains the cost for each of the routes procured by the auction. Table 5 contains a sample of eleven contracts drawn from the governmental website and standardized for comparison with the route auction. From Tables 4 and 5, it can be seen that the average equivalent contract prices achieved through the auction, AU$695, is slightly lower (about 1%) compared with the commercial contracts reported, AU$703. There is no statistical difference between the sample of commercial contracts and the prices of the auction. However, as will be noted below, the service quality outcomes (travel times for children) are better for the auction contracts. This is an important observation because it suggests that the auction approach was able to produce a better service at no higher cost.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AU$807</td>
<td>AU$733</td>
<td>AU$666</td>
<td>AU$653</td>
</tr>
<tr>
<td>AU$745</td>
<td>AU$723</td>
<td>AU$665</td>
<td>AU$648</td>
</tr>
<tr>
<td>AU$743</td>
<td>AU$689</td>
<td>AU$661</td>
<td></td>
</tr>
</tbody>
</table>

8.3 Routes and Bus Travel Times (Children’s Time Riding the Bus)

Data on the bus travel times are available from the first semester of school operation. Three questions are posed as assessments of the route determination models and methodology. (1) Were the models of transportation time accurate? (2) Were the goals met? (3) What were the impacts on individual students?

As stated previously, the routes were designed to deliver the children to school, with ride time limited to one hour. A separate bus operated on each of the seven routes collecting children
from the designated pickup stations. The structure of the routes was based on a purely theoretical model. After the auction, the winners put buses into operation and supplied performance data.

Each bus maintained a log of travel times and stops. The data from those logs are the basis of the evaluation reported here. Table 6 contains data for each of the seven routes collected from the records of the bus drivers. The table also contains the predictions of the model used to determine the routes and driving times.

Table 6. Route times in minutes: model and actual for AM and PM.

<table>
<thead>
<tr>
<th>Route</th>
<th>Route time in minutes (one way) for average transportation to the school, return and total Daily (minutes).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>model minutes</td>
</tr>
<tr>
<td>1-Fawkner</td>
<td>55</td>
</tr>
<tr>
<td>2-Heidelberg H</td>
<td>57</td>
</tr>
<tr>
<td>3-Whittlesea</td>
<td>59</td>
</tr>
<tr>
<td>4-Brunswick</td>
<td>57</td>
</tr>
<tr>
<td>5-Northcote</td>
<td>53</td>
</tr>
<tr>
<td>6-Eltham</td>
<td>46</td>
</tr>
<tr>
<td>7-Richmond</td>
<td>57</td>
</tr>
<tr>
<td>totals</td>
<td>384</td>
</tr>
</tbody>
</table>

Note: error in route four reflects an incorrect address used in the model.

The goal was to limit the time on the bus to one hour both to and from school. The model predicted that all routes would meet that condition. The model predictions for one-way travel are in the first column and as shown in Table 6 the predicted times are close to the constraint (three or less minutes on four of the seven routes). The actual travel times (both AM and PM) are in Table 6.

In terms of performance, the goal of no more than one hour on the bus was met.
The model was least accurate for morning travel with an average error of five minutes per route. The model was more accurate in the afternoon, with the average error of -0.57 minutes. Over the 14 daily trips (seven routes, two times per day) the average difference between the modelled and actual trip time was 31 minutes or about two minutes per trip.

The overall goal was total travel time less than one hour per trip (14 trips per day) or a total of 840 travel minutes was more than met, with the actual total travel time being 799 minutes. Of course, the totals mask the variances. Two routes required more than the goal of one hour, with one requiring seven extra minutes and the other requiring one extra minute. Some routes required less than an hour, which lowered the total driving time between all of the buses.

For comparison of travel times, students using the previous bus service were arranged from the shortest travel time (the fastest) to the longest (the slowest). Students using the new service were also arranged from the fastest to the slowest. The minutes traveled by the student are arranged in Figure 4 according to the percentage of students that had shorter travel times. As illustrated in the figure the experienced travel times on the new routes completely dominate (are shorter) along the new routes as compared to the old routes. The shortest travel time of any student on the new routes is 4 minutes as compared to 29 minutes along the old routes. In the AM trip the students with the longest travel times on the new routes is 54 minutes as compared to 115 minutes of the longest student time on the old routes. The afternoon times are longer.
Measurements from the corresponding quantiles are compared, as are the travel time of the marginal student in each quartile and the percentage of time saved. Table 7 provides a comparison between the old travel times and the new times resulting from the implementation of new routes. Shown are the travel times of the quartiles of students on both old and new routes.

When old routes were in use, the students with the shortest 25% of travel times were in transit for up to 47 minutes. By contrast, the students in the shortest 25% of ride lengths are in transit for no more than 15 minutes with the new routes. Thus, for the students with the shortest travel time the time reduction for the marginal student is 32 minutes. The total travel time saving for the group is 68%. The time savings for each quantile is similar with the time saving increasing for those with the longest times on the previous routes. Students that previously had the longest travel times on the bus have the greatest reductions in travel time. The 25% of students with the longest times when the old routes were in use had travel times between 90
minutes and 115 minutes one way. With the new routes the 25% of students with the longest rides are on the bus between 35 minutes and 54 minutes one way. The total travel time savings is 53%.

Table 7: Maximum travel time by quartile of students - comparison of previous and new.

<table>
<thead>
<tr>
<th>Quartile</th>
<th>Old Routes: Previous service (minutes)</th>
<th>New Routes: Auctioned service (minutes)</th>
<th>Reduction in travel time for marginal student (minutes)</th>
<th>Travel time saving as a percentage of previous time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>47</td>
<td>15</td>
<td>32</td>
<td>68 %</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>70</td>
<td>24</td>
<td>46</td>
<td>66%</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>90</td>
<td>35</td>
<td>55</td>
<td>61%</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>115</td>
<td>54</td>
<td>61</td>
<td>53%</td>
</tr>
</tbody>
</table>

9. Design Consistency: Does it Work for the Right Reasons?

The analysis of the auction begins with comparisons among theory, experiment and auction data. The preceding Section 8 above addressed the first assessment criteria, proof of principle - that the new process did what it was designed to do. This section moves to the second assessment question. Did the results occur for the right theoretical reasons? Did the auction satisfy “design consistency” in the sense that the principles used in the design account for success? That is, did the auction work as expected and work according to the theoretical principles used to structure the auction architecture? Or, alternatively, was the auction outcome the results of some random (lucky) event including possibly inexplicable properties of bidder behavior?

The game theory model used throughout the analysis reflects very broad principles of decisions as determined by individual preferences and the auction rules. The model holds that the primary motivation of bidders is to make money. In the absence of confusion and collusion, a

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9 A host of variables can be at work to shape preferences and thus outcomes. Bidders learn but can also make mistakes, operate under misconceptions or misperceptions. Tempers can flair or bidders can be distracted. According to the theory the possibility exists that a host of phenomena can influence bidder purposes, goals and preferences.
bidder will follow a dominant strategy and continue to bid lower on a route until the price is near the minimum price a bidder will accept. Given traditional models of preferences, the minimum exists and is measured by the (opportunity) cost of the resources required to supply the service. The bidder will not supply transportation services if there are better uses of the bidder’s time and resources, the bidder’s opportunity cost. The opportunity cost is the maximum benefit/payment available to the bidder if the bidder uses the resources somewhere else.

The basic principle guiding the auction design was the “best response” model from game theory. The auction is purposefully designed to limit variables on which a bid can be conditioned as it is shaped to replace the existing leading bid. Bidders do not know other bidders, the number of bidders or the pattern of bids. They are assumed to know own cost with certainty. This dynamic leads to the least cost bidder winning at a price equal to the price of the next to last bid minus the decrement requirement of AU$25.

The best response model used in the design of the auction to capture individual behavior. A direct interpretation of the best response strategy is that new bids will satisfy the minimum decrement of AU$25. Thus, according to the model, each new bid on route $x$, $B^*_t$, should satisfy the equation $B^*_{t-1} - B^*_t - 25 = \varepsilon$. Of the 231 bids in the auction $\varepsilon = 0$ in 224 (97%) of the bids. The seven bids that deviate, with $\varepsilon \neq 0$, had an average error of AU$15. The bidding is consistent with the best response model.

From the last two sections we can conclude that the process design satisfied both proof of principle and design consistency. It did what it was designed to do, and it did it for the right reasons. The focus now turns to the generality of such results.

10. Auction Outcome and Robustness Analysis ("Internal and External Validity")

The issue of robustness, the third assessment question raised in Section 1, is related to the generality of the principles reflected in the design. Basically, is the theory and thus the auction
outcome robust in the sense of producing reliable predictions when applied to theoretically similar environments? The question is naturally focused on experiments and a closely related discussion of “external” and “internal” validity.

The data reveal that the auction proceeded with bidding among competitors driving prices down. According to theory, bidder’s preferences for routes (opportunity costs) are measured when bidders stop bidding on routes. While the opportunity cost is known only to the bidder, it becomes measurable when the bidder drops out of the bidding as the lowest bid a bidder submits for a route. Thus, as prices fall and bidders drop out of the competition, the opportunity cost of each bidder on each route is revealed. An exception is the opportunity cost of the winner, which is not known in absolute terms but is known to be below the price of the final, winning bid.

While the preferences of bidders are not observed directly, the theory predicts that bidders will stop bidding when the price minus the decrement requirement is less than the cost of operating a route. Therefore, theoretically, the dropout prices reveal the (opportunity) cost known to the bidders. The question posed by robustness tests is the generality of the principles use in the theory. That is whether an auction with the same costs used as parameters would produce the same prices. Of course, the bidders would be different, students as opposed to businesspeople, and the scaling of incentives would differ but through the lens of the theory the environment would be the same. The questions posed for testing are if the winning routes are the same and if prices differ only by the same scale. The revealed preference (opportunity cost) data produced by the auction and the theory, can be combined and used for deeper tests of robustness and reliability of the model.

According to theory the bids observed in the auction reflected alternative uses (the opportunity cost) of a bidder’s resources. The bidder stops bidding when the value received from a winning bid would not exceed the best alternative use of the bidder’s resources as perceived by the bidder. That is, the bidder stops bidding when the value of winning (minus the decrement
requirement) does not cover the bidder’s opportunity cost of the resources to be deployed to deliver the transport service. The observed dropout bids, interpreted as the opportunity cost of all bidders in the auction but one, are contained in Table 8. Exceptions are the winning bidders who were not forced to drop out. Thus, the “bottom price” of the winner was not revealed but a bound is placed on the winning bidders cost because the cost to the winning bidder must be below the winning price.

Table 8: Bidder Approximate Values (AU$) Revealed in the Auction and Used as Parameters in Robustness Tests.

<table>
<thead>
<tr>
<th>Route</th>
<th>ID 321</th>
<th>ID 322</th>
<th>ID 323</th>
<th>theoretical equilibrium AU$/day (ID with value)</th>
<th>buyer ID: cost below final bid (Cost AU$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>640</td>
<td>560</td>
<td>1335</td>
<td>640 (321)</td>
<td>322 (560)</td>
</tr>
<tr>
<td>2</td>
<td>675</td>
<td>615</td>
<td>730</td>
<td>675 (321)</td>
<td>322 (615)</td>
</tr>
<tr>
<td>3</td>
<td>885</td>
<td>670</td>
<td>735</td>
<td>735 (323)</td>
<td>322 (670)</td>
</tr>
<tr>
<td>4</td>
<td>725</td>
<td>660</td>
<td>1260</td>
<td>725 (321)</td>
<td>322 (660)</td>
</tr>
<tr>
<td>5</td>
<td>545</td>
<td>610</td>
<td>1310</td>
<td>610 (322)</td>
<td>321 (545)</td>
</tr>
<tr>
<td>6</td>
<td>595</td>
<td>660</td>
<td>785</td>
<td>660 (323)</td>
<td>321 (595)</td>
</tr>
<tr>
<td>7</td>
<td>825</td>
<td>760</td>
<td>1285</td>
<td>825 (321)</td>
<td>322 (760)</td>
</tr>
</tbody>
</table>

As a robustness test of the theory, five experiments were conducted in which the (approximate) bidder preferences (costs) revealed by the auction were then induced in subjects in an experiment – using traditional laboratory experimental method of control. If the general theory applied to the complex field environment is robust then it should hold in the simple and special case studied under laboratory conditions. A classical methodological question about the relationship between laboratory experiments and field events is reduced to a simple test. While the participants are different, if the preference tradeoffs are the same in an experiment as preferences that existed in the actual auction and if the rules and restrictions on the bidders are the same, then are the outcomes the same? The equality of auction outcomes across these different experiments would provide evidence of a robust theory in the sense that the general principles of theory, as opposed to the context created by many unobserved variables found in
the application, operate to shape the outcomes. The evidence would suggest that the principles of economics found working in the laboratory are the same principles found working in the field.

In five experiments, experimental subject bidders were provided with seven items and given the opportunity to either sell the item at auction or take an outside offer of money for the item. Except for a scaling factor used to compensate experimental subjects, the opportunity costs in the experiment are (approximately) the same as those revealed in the auction. Stated in numerical dollar terms the values are contained in Table 8 are used in the experiments. Thus, in numerical dollar terms the subjects faced the same costs and benefits as the sellers in the route auction. Just as in the actual auction, subjects in the experiments could choose the outside option at any time during the auction and that choice would remain private information. The item sold to the outside offer could not be sold at the auction and an item sold at auction could not be sold to the outside offer. According to theory, the bidders in the experiments will stop bidding and sell to the outside offer if the action price falls below the outside offer. However, if the seller is able to sell at an auction price above the outside offer, then the seller will sell in the auction.

Prices in the experiments should be the same as the prices in the auction. Hence, through the lens of the theory, the experiments and the auction are close in stated dollar terms and in the procedures, but the real and factual differences are dramatic. In the experiments, the bidders are students motivated by incentives comparable to a typical hourly income of students. The currency in the experiments were in terms of an experimental currency called “francs” worth $0.004/franc. By contrast, bidders in the route auction are seasoned professionals/businesspeople and the scale of each dollar bid was in terms of hundreds of thousands of dollars over a three-year period ($/bid) (200 days per year) (3 years)). Thus, the AU$ value of a dollar bid in the field auction, i.e., on the order of AU$400,000-$500,000, was about 120,000 times the US dollar value of a bid unit in the experiment by students.
The question posed as a test of theory can be made precise. If the rules are the same and if the incentives differ only by a scaling factor, then do the results from experiments with student bidders and the results of the actual auction with professionals differ only by the scaling factor? Of course, the unknowable remains unknowable. We do not know (and possibly cannot know) how those business bidders would behave if the magnitudes were scaled down or how those student subjects would behave if the magnitudes were scaled up. However, we can test the theoretical isomorphism between the bidding of professionals and the students bidding at a reduced scale.

Result 1: experimental replications and robustness tests demonstrate that the outcomes of the actual auction and the scaled experiment differ only by the scaling factor - isomorphism holds. The results of the final prices of experiments with induced preference subjects differ only by the scaling factor from the results of the actual auction with bidding done by business professionals motivated by profits as they see them. Five experimental replication tests were performed. In all such tests, the actual auction procedures were used (323 could bid only on items 2, 3 and 6). The experimental outcomes are in Table 9. Figure 5 illustrates that a close statistical relationship between theory and experiments is supported by regression.\(^{10}\)

A second test of robustness is also available based on the bidding in the five experiments used for replication tests. The auction design rested on the game theoretic principle of “best response” given the information available to the bidder at the time of decision. As was discussed above (Section 9) new bids will incorporate the minimum decrement of 25. So, each

\(^{10}\) Variable labels and experimental indices are designed to locate data in large experimental data sets.

<table>
<thead>
<tr>
<th>Regression Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
</tr>
<tr>
<td>R Square</td>
</tr>
<tr>
<td>Adjusted R Square</td>
</tr>
<tr>
<td>Standard Error</td>
</tr>
<tr>
<td>Observations</td>
</tr>
</tbody>
</table>
new bid $B^*_t$ on route $x$ should satisfy the equation  $B^*_t - B^*_{t-1} - 25 = 0$. Figures of the bidding data are in the appendix.

Result: a total of 1040 bids were placed on the seven routes in the five experiments. Of the 1040 bids placed a total of 27 (.026) failed to satisfy the equation; the revealed bid decrement was more than AU$25. While the average decrement across all experiments was AU$59 as opposed to the theoretical AU$25 about half (14 of 27) of the deviations from the model occurred in experiment 190606 and are related to bidding errors at the opening of the auction. With the problematic bids (obvious mistakes) removed, 13 bids remain from the other four experiments with an average per bid deviation from the model of 24.5. Clearly, the modal bid is to bid AU$25 less than the existing bid. The best response model is supported in the five replication experiments. In that sense the bidding patterns in the replication experiments are similar to those of the actual auction.

The experiments appear to survive a robustness test providing useful information about the relationship between the theory, laboratory experiments and the performance of the field auction.  

Table 9. Experiments with revealed values induced.

| Theory: prices revealed in auction and prices revealed in robustness experiments |
|-----------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| item | Theory: Prices Revealed in Auction (AU$/\text{day}) | robust exp. 1 190123 pd3 (F/\text{day}) | robust exp. 2 190123 pd4 (f/\text{day}) | robust exp. 3 190606 pd3 (F/\text{day}) | robust exp. 4 190803 pd1 (F/\text{day}) | robust exp. 5 190803 pd2 (F/\text{day}) |
| 1 | 640 | 635 | 650 | 650 | 620 | 625 |
| 2 | 675 | 650 | 700 | 675 | 650 | 650 |
| 3 | 735 | 743 | 725 | 800 | 700 | 725 |

11 The time series of individual bidding in the auction laboratory experiments are contained in the appendix.
The concept of robustness is related to a methodological discussion of “internal validity” and “external validity” found in the experimental literature. The two concepts of “validity” are developed for notions of causality in the context of hypothesis tests, typically a measurement from a controlled laboratory experiment to be compared to a measurement taken from a field environment. By contrast “robustness” tests focus on properties of system behaviors and process behaviors with the focus on complex patterns of outcomes, e.g., convergence, in response to parameter changes as predicted by broad, possibly competing principles of process behaviors. Often the underlying model is very general with multiple equations and random variables that apply to different and sometimes incompletely specified environments. How statistical models of accuracy and causality, which are the substance of internal and external validity, might be incorporated in models of systems and underlying theory are challenging issues. For discussion of internal and external validity see A.J.H.C. Schram (2005) and the updated discussions in J.B. Kessler and Lise Vesterlund (2015).
11. Summary and Conclusions
The research addresses market processes associated with the large and growing government services provision sector. The sector growth is accompanied by a belief that government provision is needed due to a range of conditions leading to inefficiency or breakdown of services if provided through privately structured markets. Of course, government provision can also be inefficient, so natural questions emerge about possible divisions of functions among private sectors and government administrative processes. Exploring the question acknowledges the fact that advancing theory, computational and communications technology can play an important role in determining how and where efficient economic activities might be housed.

The broad issues are explored through the lens of a special case that brings abstract theoretical concepts into operational view. Among the numerous tasks associated with the school transportation problem, three broad areas stand out as natural for government administrative processes: (i) the development of transportation objectives with the parents, (ii) the construction of routes and (iii) the process of purchasing transportation services. A close look revealed that each of the broad areas consists of tasks that might be solved by the application of more decentralized processes. The challenge was to develop and implement appropriate processes while recognizing inherent interdependencies. Other policy related regulations must also be integrated.

The steps of establishing objectives and goals were determined through a collective decision process involving parents, teachers and school administrators. The goals were based on quantitative features that could support a more decentralized, contract perspective. The variables included the time children would be on the bus and candidate locations where children would meet for pickup. The discussions included contingency options related to uncertainties and unforeseen circumstances.

Given clearly stated goals, route determination was technical and practical. The technical issues were driven by the combinatorial problem of determining optimal routes, together with goal
simplifications that made the problems tractable and “business contract friendly”. Variables existed that could easily expand the problems beyond computational capacities. These included the interdependences among the number and location of pickup points, the number of routes and the number and size of vehicles. Practical issues were driven by the possibly unreliable street maps, bus-prohibiting tunnels, time of day traffic flows and local conditions that might reflect stop lights, road repairs, weather issues, etc.

With routes and services defined (essentially transformed into “commodities”), the private sector and competition could be harnessed for efficient delivery. Standardized administrative processes were available for the “due diligence” functions of determining qualified transportation providers regarding safety issues.

With appropriate background conditions in place, a new form of decentralized auction was employed to accommodate the routes, the severely limited number of competitors and the probity rules the government imposed. The seven routes were allocated to three bidders with one bidder restricted to bidding on only three of the routes.

The auction did what it was designed to do. No evidence of collusion exists, and the transportation cost is comparable to other procurements of transportation services. The auction required only twenty minutes for an AU$2,922,000 procurement. By comparison, the old administrative process historically required up to several months to complete. The goal of no student on the bus for more than one hour was met, with the time the average student is on the bus reduced by 60.75%.

The mechanism performed for the right reasons. The performance is due to the theoretical principles used in its design, thus establishing both a proof of concept and consistency of design with theory. The success was not an accident. An experimental robustness test demonstrates the point. The theory of the auction predicts that bidders follow a “best response” strategy and stop bidding on a route when the bid price falls to the bidder’s opportunity cost. The final
auction prices compare well to prices in previous transportation procurements and thus provide evidence that the final auction prices in the auction are the opportunity costs of the bidders. When the final prices are interpreted as opportunity costs, scaled as needed and imposed in subsequent experiments, the theoretically predicted equalities are observed. A close relation exists between the experiments and the performance in the naturally occurring environment. Individual bidding strategies follow the game theoretic best response model. The dropout prices in the experiments are equal to the opportunity costs as predicted, which are equal to the (appropriately scaled) dropout prices observed in the auction. The exercise provides evidence that the auction principles survived both scale and bidder characteristics (students and businesspeople) and the principles operated the same in the experiment as they did in the field.
References


APPENDIX: INSTRUCTIONS

This screen image will be used to explain the auction

Functions Map

- Countdown clock resets with new bids.
- Auction ends when countdown clock reaches zero.
- Bidder ID number.

Items in auction:

Bidder 311 is the leading bidder (provisional winner) on bus routes 3 and 5 displayed in color.

PIC 311 is not the leading bidder on bus routes #1 or on other routes without color. Other bidders are provisionally winning (leading) on the uncolored routes.
Fashioning and placing bids

1. Click on route if you want to place a bid
2. Selected route will appear
3. Current price minus required decrement will appear
4. Buttons allow bid adjustment
5. Click to submit bid

Auction Ending

New bid clock is reset when new bid accepted
Flashing lights warn when countdown is close to zero. At zero the auction ends.

Colored bid price means 311 is the leader (provisional winner).
Bidder Strategies and Auction Management

Administrative actions to control the pace of the auction include:
1. required decrement for bids can be increased or decreased
2. countdown clock times can be made shorter or longer.

Generally speaking, there are no benefits for waiting until the last seconds to place bids. No one will be surprised or caught off guard because the clock will reset after each bid and give other bidders time to adjust to new bids. Such waiting and last second strategies will simply delay the ending.

We know of no advantage related to delaying your bidding or waiting. It just helps the others by giving them time to think and slows the auction. Thus, last seconds bidding is discouraged and will result in shorter countdown clock times.
APPENDIX: DYNAMICS OF MARKET CONVERGENCE IN EXPERIMENTS REPORTED IN TABLE 9 USING REVEALED COST AS PARAMETERS AND AUCTION RULES (Actual Auction Figure Included).