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A TESTBED EXPERIMENT OF A (SMART) MARKET BASED, STUDENT TRANSPORTATION POLICY: NON CONVEXITIES, COORDINATION, NON EXISTENCE

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Abstract

The paper develops and studies a decentralized mechanism for pricing and allocation challenges typically met with administrative processes. Traditional forms of markets are not used due to conditions associated with market failure, such as complex coordination problems, thin markets, non-convexities including and zero marginal cost due to lumpy transportation capacities. The mechanism rests on an assignment process that is guided by a computational process, enforces rules and channels information feedback to participants. Special, testbed experimental methods produce high levels of efficiency when confronted by individual behaviors that are consistent with traditional models of strategic behavior.

SECTION 1: The School Transportation Problem

The research[1] purpose is to develop and test a "decentralized" market based mechanism and its application to an environment with many properties capable of creating market failures. The mechanism and the environment reflect part of a proposal for the transport of children to a school specialized for students with severe disabilities.

The school is dedicated to providing the children with the best possible education. The disabilities range from being blind, deaf or aphasic to the severely physically disabled (wheelchair confined), mentally challenged or severe behavioral problems (requiring almost constant supervision). The disabled children's homes are scattered around a large urban area. Special transportation services are required. Getting the child to school is listed among the most difficult challenges that the families face.[2] The current transportation service, constructed from

[1] The research support of the John Templeton Foundation is gratefully acknowledged. The policy insights of Gary Stoneham of the Center for Market Design at Melbourne University were important for structuring the research, parameter development and location for a possible field trial. The authors thank him for his help, which was a central part of the research. While the focus of this paper is on the mechanism and related technical aspects, the structure has been substantially influenced by the facts and policy insights of the Center for Market Design and the support provided by the Australian National Disabilities Insurance Scheme. The insights and cooperation of the schools under consideration for a pilot experiment are gratefully appreciated in addition to the school administrators, parents and firms in the local transportation industry.

[2] The context of the research can best be understood against the complexity of the transportation problem. The school is a magnet school located in Victoria, Australia, that specializes in education for disabled children grades K thru 12. The parents of students often cite transportation to and from school as one of the most difficult problems

government-supplied buses, is expensive and involves considerable time required on the buses (up to four hours). The proposal is to replace the governmentally supplied bus system with a market based system in which parents would contract for transportation services using grants provided by the government. The background question posed for research is whether a market based policy that draws on competition within the local transportation industry is feasible and if it can do a better job compared to the governmentally supplied bus.

The underlying economic environment contains economic conditions well known as causes of market failures. Natural models of market mechanisms based on classical institutions have no competitive equilibria due to coordination problems, asymmetric information, thin markets and zero marginal costs due to non-convexities. In the absence of an alternative mechanism the governmentally supplied bus is the natural alternative.

A two sided (smart) bidding mechanism built on principles of matching and stability suggests itself as a market based option. Abstract theory (matching with side payments), experience with smart markets (combo auctions) and even classical institutions (specialists and market makers) suggest a two sided auction-like process as a possible acceptable alternative.

The research explores a step toward a field test of a policy option by examining environments that contain key major problems even though it does not contain all of the potential problems. Experiments reported here are scaled down and while the supply side is active with continuous bidding, the demand side is passive with bids submitted once and remain unchanged throughout the auction. These simplifications allow the study of key features of the mechanism before additional complexities are implemented.

SECTION 2. A Testbed Experimental Approach

Testbed methodologies are positioned as steps to a field trial in light of the complexities and problems likely encountered. The complexity of the field can far exceed that of any laboratory testbed. A testbed is viewed as a first step in a series of steps to refine and improve the mechanism through a process in which theories emerge in the light of experience and goals evolve as expectations of the possibilities become modified. The objective of the testbed is to identify events that could lead to policy failure and in the light of theory, adjust the mechanism to avoid them.

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they face. Specifically, the expectation for quicker trips to school, smaller busses, revised pick-up and drop-off arrangements and closer assessment of children according to their supervision needs are seen as ways to improve the quality of the school travel service. From the school's perspective, the arrangements are anticipated to reduce stress on students (particularly younger students) resulting in learning and behavior gains at school. The physical arrival and departure arrangements as well as staff arrangements needed for the pilot have been developed at the school. Furthermore, a process to assess student travel needs, behavior assessments and travel preferences has been developed and is ready to implement.

2.1 Testbeds and Theory.

The testbed experiments are exploratory by nature and are used where other methodologies have limitations. A theory testing approach is sometimes not realistic because a complete, well developed and precisely defined theory might not exist. Similarly, measurement methods where the experiment is designed to produce a measurement of some parameter, need not be appropriate. Examples of measurement methods include experiments designed to measure beliefs, willingness to pay of some select group of people or elasticity of a demand or a supply for a commodity, none of which are central to the research reported here. An exploratory approach offers itself when there are neither parameters to be measured through a controlled experiment nor an understanding of the conditions under which measurement might be meaningful.

The testbed approach is very much engineering in the sense of the construction of a mechanism followed by a study of its operation in simple cases. The purpose is to identify and correct sources of problems as guided by special case theory, principles and scaling up in terms of size and complexity. The data analysis rests on seeking the answers to two questions: (i) does the mechanism do what it is supposed to do and (ii) does it do it for understandable reason, i.e. the behavioral principles used in the design process.

The testbed experiments reported here incorporate lumpy supply primarily caused by different sized vehicles as dictated by potential suppliers from the local transportation industry. Coordination problems are caused by student locations and time/distance constraints on routes. The mechanism is two sided but the buyers submit fixed bids for rides reflecting the fact that the first pilot test would have the government bidding for students by placing a fixed, private bid for a ride.[3] The environment is such that the equilibria of standard models, like the competitive model, do not exist. Consequently, the efficiency of a decentralized competitive process is not guaranteed.

While there is no complete theory that might support an appropriate mechanism, a body of principles have been successful under other circumstances and can be applied to guide a step by step process of mechanism construction. The broad principles are the tools that carry the results of controlled experiments to the more complex and untested field pilot. The experiments focus on the reliability of those principles for supporting a design and on their robustness to remain reliable within broad and complex environments.

[3] The policy preferred by the government is a fixed subsidy grant to families with disabled children but the size of the grants and other administrative controls (reflecting anticipations of moral hazard problems) are under development. Similarly, the testbed is restricted to only a ride and does not include other features such as wheelchairs, supervision in transit, special medical equipment, home pickup, time of day options, etc. Computational complexity, speed of auction, bidding processes and other challenges can be added once the basic issues are resolved.

2.2 Research Questions.

Evaluation rests on the answers to two questions[4]:

1. In the testbed environment does the mechanism do what it was designed to do?

2. Does it do what it does for understandable reasons? Can we use the principles used in the design to explain behavior observed in the testbed?

SECTION 3. Mechanism

3.1 Overview.

The mechanism is an iterating (continuous) “assignment” or “matching” system with “side payments” in which direct transactions between buyers and sellers do not take place. In fact, buyers are not buying exactly what the sellers sell and instead are buying “features” of what the sellers provide. A buyer pays for an assignment to a ride on a properly equipped vehicle that will pick up and deliver the buyer at a location of choice. Sellers make variously equipped vehicles available for a price regardless of the number of passengers that happened to be transported on the vehicle. That is, if the seller's vehicle is used at all then the seller receives the entire asking price and if the vehicle is not used then the seller receives nothing. Thus, prices are non-linear. Bids are made and adjusted in light of other bids. When the mechanism stops, the money passes through the mechanism - from the rider to the mechanism and then from the mechanism to the transportation supplier - which makes a profit and pays for resource use.

Whether or not a potential rider is assigned to a vehicle depends upon features required in a bid, the amount of the rider’s bid, the bids of others, the location of the bidder and the amount vehicle suppliers ask for the use of their vehicles. Whether or not a vehicle supplier’s vehicle is used or not also depends on the same class of variables. The mechanism considers all bids for rides, the locations of bidders and all asks for vehicles. Then it organizes transportation to maximize the cost/benefit notion of social welfare under the assumption that bids reflect marginal values and asks reflect marginal costs.

The mechanism is two sided in which both buyers (passengers) and transportation suppliers (sellers) make offer decisions and the mechanism itself plays the role of a “middleman” that informs, coordinates and enforces the rules. The interpretations of bids and asks come from the foundations of cost benefit analysis. Bids are interpreted as an informed maximum willingness to pay and asks are interpreted as an informed minimum willingness to accept. The difference

[4] These questions were first introduced by Plott (1994) as a way to apply experimental methods to policy issues and answer questions that classical approaches to the use of experimental methods could not answer. The questions are central to the methodology used in the testbed experiments and subsequent field application reported in Plott, Lee and Maron (2014).

between bids and asks is interpreted as gains from trade which the mechanism attempts to maximize minus a “mechanism surplus”, which is interpreted as a cost of social organization. The difference between the payments by the buyers and the receipts of the sellers represents a “mechanism” cost or “transactions” cost. How this difference is interpreted can differ from application to application and according to the ultimate use of the funds. We use different measures of efficiency as part of measuring mechanism success.

In several respects the mechanism is similar to an electronic broker that puts sets of buyers together with sets of sellers. Sellers are paid what they ask and buyers pay what they bid and receive the service requested in the bid. The difference between what buyers pay and what the sellers receive remains with the broker. However, the built-in objectives and incentives used to guide mechanism decisions systematically differ from the incentives of brokers. A broker takes action to maximize own profits. As shown in the Figures 1 and 2, (e.g. with limited competition and constant buy and sell prices) when the brokers keep the difference, they have an incentive to restrict transactions. That is, brokers would have the incentive to restrict demand to keep cost of supply down and restrict supply to keep the prices up. By contrast the incentive of the mechanism is to maximize the gains from trade with no incentive to restrict trades at all.

Figures 1 and 2 go about here

The empirical questions turn on participant behaviors and the resulting system behavior. Will it operate to maximize gains from trade when participants are involved in a decentralized environment with no information about the preferences of others? Will this performance depend on the environment?

The formal structure of the general mechanism is similar to the classical general equilibrium system. The system seeks to find an “assignment” for which the underlying system and resource constraints are satisfied. As the mechanism attempts to guide bids and asks to an assignment, it iterates as is illustrated in Figure 3. Buyers tender bids and sellers tender asks. Winners are the agents who are part of the assignment as determined by the mechanism. Buyers in the winning assignments pay the amount of their bid. Sellers whose vehicle is part of a winning assignment are paid what they ask for the vehicle.

Figure 3 goes about here.

With each new bid or ask the system solves a maximization problem subject to the economic constraints dictated by the environment. Specifically, the mechanism selects “provisionally” winning bidders and “provisionally” winning vehicles that become winners when the system terminates. Provisionally winning bidders are assigned to vehicles consistent with vehicle capacity and the vehicle routes that are consistent with assigned passenger locations. Decisions depend on decentralized, strategic bidding behavior reflecting information feedback, beliefs about the decisions of others and related system behavior as it moves toward a theoretical equilibrium. If behaviors are not properly aligned with underlying incentives or if they are not properly coordinated, then system efficiency will suffer.

Increment requirements and countdown clocks are used to guide the system to an equilibrium. Two countdown clocks provide incentives to submit timely bids and asks, as opposed to strategically waiting. Each clock resets to a fixed (and public) time and counts down. If either clock reaches zero, the mechanism ends and the provisional winners become winners. One of the clocks, a new bid clock, resets with each new bid or ask and then starts counting down again. Its purpose is to encourage the timely arrival of new bids and the search for matches. However, because new offers need not result in new assignments, continuous strategic negotiations could keep the auction open with no actual changes in assignments. In order to avoid such mechanism failures, the second clock, a new winner clock, resets with new assignments and then resumes a countdown. Thus the new bid clock encourages bidding while the new winner clock puts pressure on achieving an assignment.

3.2 The Formal Structure and Notation

A general model is outlined below. The experimental test is a much simplified and special case version but the general model is important for an understanding of the role played by the testbed in the context of the bigger problem. In essence the experimental testbed involves a reduction of the number of variables but the relationships in the model remain. The larger application will require more computational time and different screens for feedback and decisions.

Italics means the variable is to be determined by program.
Lowercase means that the variable takes on only 0 or 1 values.
Bracket means a matrix.
The non-italic means parameter or set.

$n \in \mathbf{N}$ = the set of students (student is location specific and only one student per location)
$j \in \mathbf{J}$ = the set of vehicles
$q \in \mathbf{Q}$ = a quality or type of service
t = a type or style of vehicle. In this model “features” are a characteristic of the vehicle and possibly subject to control by the vehicle owner. This issue is of concern in policy discussions and is included here to illustrate how it is consistent with the model.
S_j = capacity of vehicle j
J_r = the set of vehicles owned by vehicle owner r
$R_t \subset J_r$ = a subset of vehicles offered by owner r that are a reconfiguration of a particular style of vehicle called type t.
$m \in M = \{1,3,....\mathbf{M}\}$ = the set of all routes dictated by the set of students to be picked up by a specific vehicle. These are determined independent of the program and implemented as simply a subset of the logical possibilities.
L_{im} = 1 if child i is on route m and 0 otherwise
d_m = distance associated with route m. It can be in terms of miles, cost or time.

Q_{qj} = 1 if service q is available on vehicle j and 0 otherwise.
B_{nj} = the bid by student located at i for vehicle j. n∈ **N**, j∈**J**, Different vehicles can have difference in quality as well as services. The qualities are known to the bidder so the bid itself reflects the value the bidder places on the bundle of services associated with different vehicles.
P_j = the ask placed by the vehicle owner for supplying vehicle j; j∈**J**
(Note that costs associated with route distance are paid according to the assigned cost of the route.)

VARIABLES: these are determined as a solution to the program.
Assignments:
$A_j = \Sigma_n x_{nj}$ = number of students assigned to vehicle j
T_j = transportation cost associated with route assigned to vehicle j, j∈**J**
The transportation cost can be subtracted from the objective function. The potential routes can also be screened for cost or time and allowed only if below some threshold.
λ_k = multiplier on constraint k

[B_{jn}] B_{jn} = bids placed on vehicles j by student *n*

w_j = 1 if the ask for vehicle j is accepted (vehicle j used) and 0 otherwise (vehicle j not used)

[L_{mn}] $L_{mn} = \begin{cases} 0 \text{ if route m does not pick up student n} \\ 1 \text{ if route m does pick up student n} \end{cases}$

[z_{jn}] $z_{jn} = \begin{cases} 0 \text{ if bid on vehicle } j \text{ placed by n is not winning} \\ 1 \text{ if bid on vehicle } j \text{ placed by } n \text{ is winning} \end{cases}$

[x_{nj}] $x_{nj} = \begin{cases} 0 \ \ if\ student\ n\ is\ not\ assigned\ to\ vehicle\ j \\ 1\ if\ student\ n\ is\ \ assigned\ to\ vehicle\ j \end{cases}$

[v_{jm}] $v_{jm} = \begin{cases} 0 \ \ if\ route\ m\ is\ not\ assigned\ to\ vehicle\ j \\ 1\ if\ sroute\ m\ is\ assigned\ to\ vehicle\ j \end{cases}$

Maximize (objective function)
$\sum_j^J \sum_n^N B_{jn} z_{jn} - \sum_j P_j w_j$ Sum of benefits minus sum of costs
z, A, w, x, v,

subject to constraints:
(1) $\sum_n^N x_{nj} - A_j = 0 \ , j \in J$
{definition of A_j as the number of students assigned to j}

(2) $A_j - S_j w_j \leq 0$
{vehicle passengers assigned to vehicle are limited to capacity if vehicle is selected and 0 if not}

(3) $[x_{nj}]\,\vec{1}_{1xJ}$ - $\vec{1}_{1xJ} \le 0 \quad or \quad \sum_{j=0}^{J} x_{nj} - 1 \le 0\,, n \in \text{N}$
{each passenger is assigned to no more than one vehicle}

(4) $[\text{B}_{jn}] = [Q_{jq}]\,[U_{qn}]$.
{bids on vehicles are deduced from vehicle qualities and utilities placed on qualities} This step is included as an illustration of possible modification but was not used in the experiments because in the experiments the only feature of value to buyers was a ride. Instead, it is replaced by direct entry of the matrix B

r = vehicle owner, J_r is the set of vehicles owned by *r*; $\text{J}_r \subseteq \text{J}$, $\cup \text{J}_r = \text{J}$, , $\text{J}_r \cap \text{J}_{r'} = \phi$

(5) $\sum_{j \in Jr} w_j - 1 \le 0 \; for\ all\ r$

No owner has more than one vehicle chosen
$[w_{j \in Jr}]\,\vec{1}_{J_r x1}$ - 1 ≤0
In the testing constraints (4) and (5) were relaxed. (4) was relaxed because vehicles had only one feature (the ride), aside from timing and routing. (5) was relaxed because suppliers were willing to operate as many vehicles as might become winners.

(6) $[\,v_{jm}]\,\vec{1}_{Jx1} = w_j$ in summation notion it is ($w_j = \sum_{m=1}^{M} v_{jm}$)

$$\begin{bmatrix} v_{j1} & \cdots & v_{1M} \\ \vdots & \ddots & \vdots \\ v_{j1} & \cdots & v_{JM} \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ . \\ . \\ 1 \end{bmatrix} = \begin{bmatrix} w_1 \\ \vdots \\ w_J \end{bmatrix}$$

Equation (6) requires that a vehicle is assigned to only one route.

(7) $[v_{jm}]\,[L_{mn}] = [z_{jn}]$

$$\begin{bmatrix} v_{11,} & \ldots, & v_{1M} \\ \vdots & .. & \vdots \\ v_{J1,} & \ldots, & v_{JM} \end{bmatrix} \begin{bmatrix} L_{11,} & \ldots, & L_{1N} \\ \vdots & .. & \vdots \\ L_{M1,} & \ldots, & L_{MN} \end{bmatrix} = \begin{bmatrix} \sum_m^M v_{1m}\, L_{m1,} & \ldots, & \sum_m^M v_{1m} L_{mN} \\ .. & .. & .. \\ \sum_m^M v_{JM}\, L_{m1,} & \ldots, & \sum_m^M v_{Jm} L_{mN} \end{bmatrix} = [z_{jn}]$$

The matrix on the left contains the number of ways that routes can be assigned to vehicle *j* and used to pick up student *n*.

$$[\,\sum_m^M v_{jm} \quad L_{mn} \quad]_{\text{J x N}} = z_{jn} = \begin{cases} 0 & if\ the\ bid\ on\ vehicle\ j\ by\ bidder\ n\ does\ not\ win \\ 1 & if\ the\ bid\ on\ vehicle\ \ j\ by\ \ bidder\ n\ does\ win \end{cases}$$

The equation says that the expression is 1 for the pairs {j, n} for which the bid by n for vehicle j is winning and 0 for all others. Students are assigned to vehicles that are assigned routes where the student is picked up.

(8) $[v_{jm}]\,[d_m] = T_{(Jx1)}$, that is $T_j = \sum_{J=1}^{M} v_{jm}\, d_m$ when stated as a summation.

(9) $\vec{I}_{(1xJ)}\ T_{Jx1}$ = Total Transport cost $=\sum_{1}^{J} T_j$

Constraints (8) and (9) were replaced by a route filter that guaranteed that no vehicle is assigned a route that required over G minutes.

SECTION 4. Testbed Environment

Major economic parameters of the testbed are motivated by the pilot experiment environment including properties of the school, the number of students, student locations, equipment capacities of firms from the local transportation industry and policies, not all of which are known. Because the exact parameters are not known the testbed implements (economic) problems that are a bit "harder" than those anticipated.

4.1 Design and Procedures

The mechanism testbed methods rest on classical procedures used in experimental economics. Demand and costs are induced with money according to parameters known to the experimenter but are not known to the mechanism. Potential riders are given induced values for rides and features. Potential suppliers are given induced cost of vehicle operations. Participants acquire benefits through the coordination of decisions of buyers, the decisions of sellers and are measured by the flow of money that originates from buyers and ends up in the hands of sellers who cover cost. Mechanism success is measured by the net money payments to subjects relative to the maximum possible. Thus, system efficiency reflects the traditional tool of experimental economics (Plott and Smith, 1978.) as the total of gains from trade divided by the maximum possible given the imposed economic parameters. However, the mechanism under consideration is not a "market" reflecting negotiations between individual buyers and sellers typically tested through experimental economics.

A total of five experimental sessions were conducted. Each of the five sessions used four subjects who were undergraduate students at Caltech and had no experience in a similar type of experiment. Each of the five sessions contained four experimental series; Series A, Series B, Series C and Series D. Each of the four series tested the mechanism under a different set of parameters. Thus the data set was produced through five sessions with four students each (twenty different subjects). Subjects in a session participated in all four different series of the session and made multiple decisions within each series. For each subject the experiment produced four final outcome decisions, one from each series. Each final outcome decision consisted of decisions regarding individual vehicles plus many other decisions as the mechanism converged over time. Each session lasted about two hours including a training period, the data from which were discarded. Subjects earned an average of $45 each.[5]

4.2 Incorporated Field Conditions

The four experimental series, Series A, B, C and D, incorporate prominent features of the anticipated field trial where the conditions for equilibrium of classical models need not exist. Anticipated parameters were used because the exact conditions of the field trial will not be known until shortly before or even after the actual event.

Basically, key parameters were approximately half of those anticipated in the field trial.[6]
(i) Thirty two children are located at six pickup stops with group sizes (4,4,4,4,8,8).[7]
(ii) The children along the school route selected for the initial trial were reasonably self-sufficient, able to travel without specialized supervision and needed no special equipment such as a wheelchair.
(iii) No vehicle can make over four stops.[8]
(iv) Vehicle capacities are "cabs" (2 passengers) , 'mini bus" (5 passengers) and "bus" (12 passengers).[9]
(v) Four suppliers expressed an interest in participating in the field trial. Two specialize in small vehicles and two have access to large vehicles. All have limited access to the mid capacity vehicles.
(vi) Induced costs are in the range reflecting industry judgments and induced with considerable variability within a supplier.

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5 Instructions were given with a power point that subjects could study on their computer. They were also given a hard copy. The power point explained the mechanism operations and how subjects could make money. The experiment proceeded as a sequence of independent periods and subjects were paid the full amount earned each period. Payoff charts were distributed before each period.

The environment was explained as a transportation exercise in which they had vehicles that they could offer for use. The particular use of their vehicle would be determined by the mechanism and if the vehicle was not used no additional cost would be incurred. If their vehicle was used, they would be paid the amount they asked independent of the route to which the vehicle was applied or the number of passengers on the vehicle.

The instructions concluded with an exercise using their first period incentives but without money. As part of the instructions subjects were instructed to make many bids and offers just to learn functionality and to do so without regard to profits. However, after the instruction exercise they were required to calculate their hypothetical profits in order to demonstrate that they understood the incentives.

6 In order to manage the testbed experiment, the environment was scaled down by half. Once performance, including software, computation speed, effectiveness of rules, behavior and instructions were established as satisfactory the plan called for a small number of exercises at larger scale.

7 The anticipated number of children is between 48 and 52. The actual number of stops in the trial will be six.

8 The limitation on number of stops translates into a constraint that time in transit would be less than 25 minutes. By contrast the single bus used under the current policy when making all of the stops requires about an hour and a half one way.

9 These capacities are roughly half of the capacities of vehicles that the local transportation industry anticipates using.

4.3 Field Conditions Implementations:

4.3.1 Demand.

Policy considerations for the field trial reflect major simplifications of the demand side decisions relative to the most complex conditions that could be imagined. Rather than the families placing bids during an initial trial the government plans to place a fixed bid equal to allocated transportation funding. The system would operate to minimize cost and the government would pay the bid of accepted suppliers. Thus, the testbed abstracted from strategic behavior of buyers.

The initial field trial will apply to approximately 50 children. Initial experiments scale the number down to 32 for testing with a few sessions planned at full scale. In terms of initial testing parameters the market demand is for 32 units at a price of 1000 francs per child. These demand prices are unknown at the time of testing and were set high relative to expectations in order to challenge the efficiency properties of the mechanism. However, a maximum bid of 200 francs per seat was implemented to reduce the time required for price convergence.

4.3.2 Supply.

The unit of analysis is a vehicle. The costs are assigned to vehicles and differ across vehicle capacities and across owners. It is as though the owners own different models, have different maintenance policies and different drivers, all of which lead to different cost across owners for a vehicle with a fixed capacity. Table 1 contains different concepts/models of firm costs for four different sets of cost parameters, Set A, Set B, Set C and Set D are used respectively in experimental Series A, B, C and D..

Table 1 goes here

Table 2 goes here

Figures 4, 5, 6 and 7 go here

The implied models of market supply for each of the four different sets are illustrated in Figures 4, 5, 6 and 7. The 32 passengers demand is a vertical line representing a perfectly inelastic demand (up to a price of 200 per seat). Two different models of supply curves are used. One is based on accounting cost, vehicle cost per seat and the other model rests on the economic concept of efficient supply and cost per passenger. The figures also contain different concepts of market equilibrium.

For supply based on cost per seat (vehicle cost to the owner divided by vehicle seat capacity) the costs are different across vehicles. Only the vehicle cost to the owner and its capacity are considered here. The figures have supply arrayed by cost per seat from low to high. The capacity 12 vehicles are represented in a different color (shade) so the consequences of the "lumpy supply" can be assessed in the context of a supply function resting on accounting cost.

In addition to supply cost defined in the accounting terms of cost "per seat", the cost can also be defined as "per passenger" and the vehicles ordered in terms of cost per passenger reflecting market efficiency based on the value placed on units by the buyers. In Series A, the two concepts of cost are the same and supply is displayed as a single supply curve in Figure 4. Series A supply costs are the same at 32 units where the market demand cuts the market supply. As will be emphasized when the discussion turns to models of market price, two concepts of marginal cost relative to market demand are important in the classical models of price determination. An internal marginal cost is well defined for units lower than 32 (the internal margin) and an external marginal cost is well defined for units greater than 32. While the marginal costs will be important for price determination, there is no ambiguity about the vehicle since both margins apply to separate vehicles.

The need to distinguish between per seat and per passenger cost (partial fill) and thus the need to distinguish between an accounting concept of supply and economically efficient supply becomes important if partially filled vehicles are part of an efficient supply. The economically efficient supplies for the 32 units demanded are reported in Table 2 for all four sets of parameters. Notice that the efficient supply for Sets C and D has the market supply of seats at 33 seats rather than the 32 required to carry the seats demanded. That is, excess capacity is part of an equilibrium. The competing concepts of supply are illustrated in Figures 4, 5, 6 and 7 for four sets of parameters. The model that supports this computation is contained in the next section.

For the parameter Set B in Figure 5, supply of 32 seats requires 8 seats of a 12 seat capacity vehicle that costs 1188 or 99 per seat. If the vehicle is used it will have only eight passengers at a cost of 148.5 per passenger. A distinction between per seat (99 per seat) and per passenger (148.5 per passenger) clearly makes a difference. However, the least cost method of supplying 32 passengers does not include the 12 seat capacity vehicle. The eight seats needed for passengers supplied by that 12 seat vehicle (cost = 1189) can be supplied by four two capacity vehicles at a lower cost of 810 (200+202+204+204 = 810) and an internal marginal cost (per passenger) of 102. The efficient supply is shown as black circles in Figure 5.

Classical economics holds that the relevant marginal cost is the efficient cost per passenger since the passenger is the source of social benefits and thus should be reflected in any price that has resource use implications. Parameter sets C and D distinguish cases of partial fills and internal vs external margins. Set C in Figure 6 has a focus on partial fills and an internal per passenger margin of 94 as compared with an external per passenger margin of 113. Set D in Figure 7 also has partial fills with an efficient internal per passenger margin of 75 to be compared with the inefficient internal per passenger margin of 94.

SECTION 5. Models, Theory and Principles

The assessments of the laboratory experimental data focus directly on the two research questions introduced in Section 2 above. The first question to be answered with experimental data is: "Does the mechanism do what it is designed to do?" The mechanism is designed to produce an efficient allocation. Consequently, measurements are focused on efficiency. The second question is design consistency. Are the principles used in the design of the mechanism those observed when the system is actually operating? Are the observed operations of the process consistent with the theory that led to the design?

Economic policy experimental testbeds involve questions that are not addressed adequately by traditional methodologies. The data analysis for testbed, laboratory experiments differs from standard theory testing or parameter measurement.

5.1 The Design Purpose - Efficiency.

The purpose of the mechanism is to produce an economically efficient allocation of transportation resources. Given the parameters of the testbed environment, efficient allocations do exist so efficiency is not inconsistent with the logic of the tests. Full efficiency is possible and the efficient allocations are contained in Table 2 in the previous section for each of the series A-D. If, for example, the bids for transportation are perfectly revealing of preferences and if the costs are revealed in the bids of transportation suppliers then the outcome of the assignments constructed by the mechanism will be efficient. Whether or not the mechanism operates efficiently, the purpose of the design, is an empirical question. Efficiency in operation follows from no general principles. Many equilibria can exist and while some are efficient, others are not.

5.2 Design Consistency.

The second question is "Does the mechanism do what it does for understandable reasons?" The question puts the focus on the principles used to construct the mechanism. The principles used in the analysis are the "understandable reasons" that support predictions of when the mechanism will work and when it will not work. If the mechanism performance is accidental, then there are no compelling reasons to expect the performance to replicate or be successful under slightly different field conditions. Thus, the design rests on a presumption that if the principles operate then efficient outcomes are to be expected and cannot be attributed to some random events. Furthermore, a presumption exists that the mechanism will work in other environments where the principles apply even though no experiments of the alternative environments are studied. In essence the theory provides the foundation for expectations of performance robustness, which some call "ecological" or "external validity".

Three basic behavioral principles are known to operate under a broad set of circumstances and thus might be expected to guide systems behavior.

1. Bids tend to be best responses or in the direction of best responses to the bids of others.[10]

2. Mechanisms equilibrate[11].

3. The equilibration is toward a Nash stable assignment. That is, the allocations at the equilibrium are supported as Nash response strategies. No agent has a decision option that makes the agent better off given the decisions of others.

In the testbed environment the classical competitive model can be used to answer neither of the motivating questions. The student transport problem has features that are compatible with the competitive model. However, the environment also contains cases that are incompatible with competitive oriented models and collectively suggest classical forms of market organization cannot be successfully applied to produce efficient allocations. The parameters in Set A can support a "one price" equilibrium (see Figure 4) and Set B can also support a one-price equilibrium if the price is measured in terms of "per passenger". However, Figures 5 through 7 illustrate that the competitive (one price) equilibrium does not exist in Sets C and D. Hence, the question of existence and efficiency do not follow from the application of the competitive equilibrium model when applied to potentially real cases.

Fortunately, the first principle, best response, does lead to a model that is well known in the literature. The model does not lend itself to analytical techniques and computation of equilibria. However, simulation of the mechanism with robot agents following a best response bidding (best allowable price) dynamic provides surprising and useful insights for parameter sets A-D.[12] In particular, the simulations when operating in the testbed environments result in convergence to the optimal (least cost) use of vehicles. That is, in these environments the best response strategies lead to an efficient and stable match, as summarized in Proposition 1.

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[10] This form of behavior is well documented in games and in markets.

[11] The mechanism is very similar to sincere or "straight forward" bidding in multiple item, ascending price auctions that are known to converge to predictable equilibria. These strategies do not anticipate the reactions of others. G. Demange, D. Gale and M. Sotomayor (1986), "Multiple-Item Auctions." *The Journal of Political Economy,* 94 (4): 863-827.

[12] Simulation results: each parameter set is run 3 times. Because the sequence of order submission, the final results are different, with set D being most significant. Also, the bidding is done based on current state. Since each seller bids independently, it is possible the state has changed when the bid is submitted.
1. Each seller checks the current state, skipping currently leading vehicle offers.
2. For non-leading offers, if the next allowable price does not make it leading, the potential profit is calculated with: NextPrice - Cost. If the NextPrice will become leading, it computes the potential profit: NextPrice - Cost - bumped_leading_offers_profit + brought_in_offers_profit.
3. It then select the highest potential profit vehicle and submit the offer. If submitting an offer will cause the current total profit to decrease, then no offer is submitted.
4. wait 5 seconds and repeat from step 1. When no seller can submit a more profitable offer, the bidding stops and clock runs down, and market closes.
Parameters: increment is 5

Proposition 1. When supply agents use a best response strategy with any of the parameters Set A, Set B, Set C and Set D the auction (i) converges to an efficient (least cost) allocation and (ii) the resulting allocation is a stable match.

Support. (i) The numerical simulations of the mechanism contained in Table 3 demonstrate that when all agents follow a best response strategy the mechanism terminates at an efficient supply. In all but 2 of the 12 simulations the results are efficient supply. The discrepancies from the efficient supply in the two exceptions are less than 5%, the increment requirement.

(ii) Stability follows from the fact that the allocation is supported by (derived from) a best response strategy. Given the bids of others, no agent has an incentive to deviate - bid more or less than the agent's current bid.

Table 3 goes here

While proposition 1 establishes the theoretical foundation for an expectation that the mechanism will result in an efficient and stable match. As will be addressed in the next sections the classical competitive models do not provide such support. However, stable assignments or matches can exist when the competitive equilibria do not exist. The stable outcomes have been shown to emerge in markets where the competitive equilibria do not exist.[13] Furthermore, inefficient, stable matches exist in the testbed environments[14] while equilibria of the classical models do not. The empirical issues are whether the principles are at work and bring the mechanism to an equilibrium, stable assignment and whether or not the equilibrium is efficient.

SECTION 6. Results

The results address the fundamental questions regarding the mechanism and the proof of concept. Does the mechanism do what it was designed to do and is the performance consistent with the (well established) principles that led to its construction? The basic result outlined below is that the mechanism does do what it was designed to do. Furthermore, because it does it for the right reasons an expectation exists that it will also work in the field trial. The analysis led to additional results regarding price formation and supports an understanding of supplier revenues and distributions of costs.

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[13] Hatfield, Plott and Tanaka(2016) demonstrate the emergence of stable matches in cases in which the existence of the competitive equilibrium was destroyed by the imposition of price ceilings and price floors. Herings (2015) brings HPT closer to a theory of markets by demonstrating that the stable matches can be supported by fixed price equilibria (Dreze, 1975,),(Drez and Miller, 1980). That line of theory suggests that a properly structured mechanism can lead to the "discovery" of the fixed price equilibria.

[14] In the environments studied here not all stable assignments are efficient. Consider, for example Set D and suppose the three capacity 12 vehicles bid 106 and that all other vehicles bid 110. The three capacity 12 vehicles are profitable and none of the thee has an incentive to undercut. All get what they ask (e.g. cost or a little above) and do not care if they have passengers or not. Among the non-winners there are two 2's and a 5 that should be in the efficient set and are not. The allocation is inefficient. However, none of the small vehicles can make a profitable bid that will make them a winner. They can make coordinated bids but those are not Nash responses and thus the match is stable. This example leads to insights about why the mechanism does not get stuck here.

The first result addresses the efficiency of the allocations. Efficiency is defined by consumer surplus divided by maximum possible consumer surplus. However, in this testbed the focus was on cost minimization. The buyers were simply bids placed by the experimenter so the demand price has little meaning in terms of social welfare. The value of units sold is a constant K= [32 V where V = 200]. Efficiency becomes:

[(K- total cost of units sold)/(K- minimum cost of producing 32)].

The minimum cost of 32 units is the cost of the optimal supply. Efficiency equals 1 if and only if total cost of units sold = cost of optimal. As at least 32 units are produced and sold, efficiency varies directly with the cost of goods sold. Thus, cost of goods sold/optimal cost becomes a proxy for efficiency and is also a measure of "production efficiency" in the sense of the waste resulting from using an inefficient method of production. Partial vehicle fills means that the marginal cost of an additional passenger is zero and exhibits the tension with the competitive model caused by the non-convexities.

Result 1. Mechanism outcomes include partial fills of vehicles and are near 100% efficiency.

Support. The efficient allocation in sets B, C, and D involve partial fills so the efficient allocation for those parameter sets demonstrates the ability of the mechanism to efficiently include partial fills (zero marginal cost for a passenger). The efficiency results of all experimental sessions are in Table 4. The mechanism operates at near 100% efficiency. 20 experimental sessions were performed and 12 exhibited a 100% efficiency level. Only one had an efficiency loss of over 5%, higher than the incremental requirement.

Table 4 goes here

The second result is focused on stability in the sense of best responses. While the concept of stability follows from efficiency of the outcome, the property could be a consequence of a wide variety of strategies. The next proposition characterizes the decisions that lead to equilibrium and match stability if best response strategies are used by all agents.

Result 2. Outcomes are stable matches

Support. Consider the 20 experiments. A "period" constitutes an experiment. There are 4 periods each day and 5 days. There are four subjects in each experiment so we have 20 x 4 = 80 end of period individual outcomes that we examine for stability. The condition of stability reflects both structural and informational factors.

A decision is considered to be stable given the decisions of others, when there does not exist an action that (i) produces profits greater than a small transaction cost[15] of 10 francs; (ii) is

[15] In this case a transaction cost of 10 francs is assumed. A transactions costs is a well-established feature of individual preferences. Individual will not take an action without a small benefit. The use of a "trading

"informed rational" in the sense that individual decisions reflect the opportunity cost of bids on vehicles that replace their own winning bids on other vehicles[16] and; (iii) is recognized by the bidder as feasible in the sense that during the auction the individual made at least one bid on the vehicle.[17] Of the 80 individual outcomes, 23 have actions that would produce a non-zero profit but only 14 of those actions would produce profits over 10 francs and 4 of those 14 are not recognized by the bidder as feasible. Thus 70 of the 80 outcomes are stable. The pattern demonstrates that property of stability is not due to some purely random event.[18]

A model of price determination follows directly from efficiency and the best response models. The general lack of existence of competitive equilibria in the economic environments due to the non-convexities suggests that the pricing will not be consistent with the one price model. However, the non-convexities of the economic environments together with the efficiency seeking properties of the mechanism lead to a need for bidders to "fit together". That, in turn, suggests a concept of "types" that pits bidders of a similar capacity type against each other in a competition for a "slot" in the set of winners.

According to the best response model, bidders will submit bids above cost but just sufficiently low to make a contract match while preventing having the contract being replaced in a match by a competitor. The implication is that prices are set by the cost of the "external margin" bidder of a capacity type. The result is that the prices are structured as a form of "entry preventing" price. Given a theoretically efficient allocation, the excluded bidder of a given capacity type with the lowest cost per seat from among the excluded bidders of that type will be the price per seat charged by the winning bidders of that type. We call this price the "entry preventing price for a (capacity) type". However, it could be a collection of vehicles with the same collective capacity.

The entry preventing price for a capacity type is the minimum cost per seat of the excluded bidders of a capacity type. In a stable assignment, the winning bidders constitute the most economically efficient supply. The best response principle indicates that the excluded bidders of a given type will probe the market with bids near the cost per seat times the number of seats. The ultimate winner would respond with lower bids until the competition no longer exists. This feature of theory together with the continuous nature of the mechanism bidding process provides the foundation for an empirical test summarized by the third result.

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commission" or its equivalent is a universally used feature of economics experiments that is either added to models or added to payoffs (Plott and Smith, 1978).

[16] This level of rationality is natural because the mechanism reveals when a bid on one vehicle will remove winning bids on one or more of their other vehicles. For example, a low bid on a vehicle with a 12 seat capacity could replace winning bids of own smaller capacity vehicles.

[17] Sometime options in complex systems simply go unnoticed or for some reason the bidder thinks that it cannot be profitable. The consequence is that bids are not made on the option. It is as if the option does not exist.

[18] We consider the final outcome of each experiment and determine if the outcome meets the conditions sufficient for the outcome to be stable and if they are met the outcome is classified as stable. The hypothesis that stability is a random event with stability occurring with a probability of 50% or less can be rejected.

The third result demonstrates that the principles used to support the mechanism design explain the prices that evolve through the application of the mechanism in the testbed environment.

Result 3. Prices differ across capacity types and are determined by the entry preventing price for the type.

Support. The analysis proceeds in two steps. First, for each type and for each experiment, the per seat cost of the excluded bidders, those not part of the efficient allocation, are computed. The cost per seat by parameter set and capacity type are contained in Table 1.

Table 5 goes here:

The data in Table 5 provides a strong impression of the relationship between winning bids of a (capacity) type and the cost of excluded bidders of the same type. A simple regression is formulated as:

Price of winning bidder of type= a + b (price per seat of excluded bidder of type)

The model is then applied to each of the parameter sets and experiments. The regression results for the pooled data are in Figure 8. The coefficient is statistically indistinguishable from 1 and the intercept is indistinguishable from zero.

Figure 8 goes here

SECTION 7. Summary and Concluding Remarks

The project explored the properties of a mechanism designed as a tool for procuring human services in economic environments that can lead to the failure of markets organized along classical lines. The research purposes and the environments were taken from a field context where the mechanism will be implemented should success be suggested by testbed results. The focus is on the "supply side" of a problem in which a diverse set of suppliers compete for the demand as expressed by the government. Thus, the competition is "one sided" as opposed to two sided in which the ultimate users of the services, in our case the families of the children who will be using the transportation services, express willingness to pay.

The supply problem is complex. Non-convexities are pronounced. Information is private. Coordination among suppliers is part of the problem. The "lumpy" supply creates a situation where vehicles are only partially filled and thus exhibit zero marginal cost for an additional rider. The supply involves coordination among the sellers among stops and routes taken by vehicles. The complex environments are explored extensively as is a case where the data should be predicted by the competitive model. Specifically, the competitive equilibrium, the one price equilibrium, exists in only one of the settings.

The mechanism is novel. It does not exist in the field or in abstract theory. It is not supported by a unified theory and it does not rest on principles used in traditional mechanism design research and applications. The experimental methods differ from textbook methods. However, the mechanism was constructed from principles found useful in other complex environments, previous experimental work and from mechanism adjustments in the light of experimental performance. Elements of classical procedures and theories do play a systematic role.

The testbed methodology addresses two questions. 1. Does the mechanism do what it is supposed to do? 2. Does it do what it does for understandable reasons, i.e. the principles used in the mechanism construction? The first question is a form of proof of principle or proof of concept. It asks if the mechanism performs as desired in experimental environments with economic challenges similar to those expected in the potential application. The second question addresses the robustness needed for successful application. Is success due to the systematic operation of principles as opposed to a lucky accident? The mechanism will be functioning in an environment that will differ from the testbed environment. The question is whether or not theory used in the design process is robust in the presence of small change in parameters. Expectations of success are supported by the wide range of experiments in which the principles are central parts of models that work satisfactorily.

Proof of concept was established in the testbed environment. The mechanism does what is supposed to do by achieving near 100% efficiency in all testing environments. The demand was always satisfied by the least cost allocation.

The mechanism follows well established principles. The dynamic process followed a best response model often found in well performing auctions. Coordination and fitting was done by a computerized process in which bidders were pitted against similarly equipped suppliers with assignment determined by lowest bid. The process was fast with successful suppliers changing every few seconds until the process converged to equilibrium. Pricing was dictated by the excluded bidders of similar type. Thus, the most efficient supplier occupied the niche and received a price approximated by the cost of the lowest cost excluded bidder of the same type.

Simply put, the mechanism "discovers" both the most efficient allocation and the prices that support (maintain) that allocation as equilibrium. Remarkably, the mechanism produces the efficient allocation and prices that maintain the allocation (support the allocation) and thus does so without information about costs. Such results are similar to what the Dreze (1975) fixed price equilibrium and the generalizations by Herings (2015) seek to do through administrative procedures.

The results of the testbed appear to justify a field trial. The mechanism is understandable in terms of basic economic principles. A wide range of sellers can compete. Coordination over routes is automatically solved and sellers are paid an additional predetermined transportation cost for assigned routes. The structure guarantees that it will not operate at a loss and any surplus is paid to the school or some other entity. The mechanism is simple from a user point of view. Winning buyers pay their bid price. Winning sellers pay their asking price. Users are not exposed to the possibility of loss. Thus success is not simply an accident and a presumption exists that it will work under multiple different field conditions. This testbed result justifies taking the mechanism to a field test.

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FIGURES AND TABLES

Figure 1. System Surplus Under Transport Mechanism

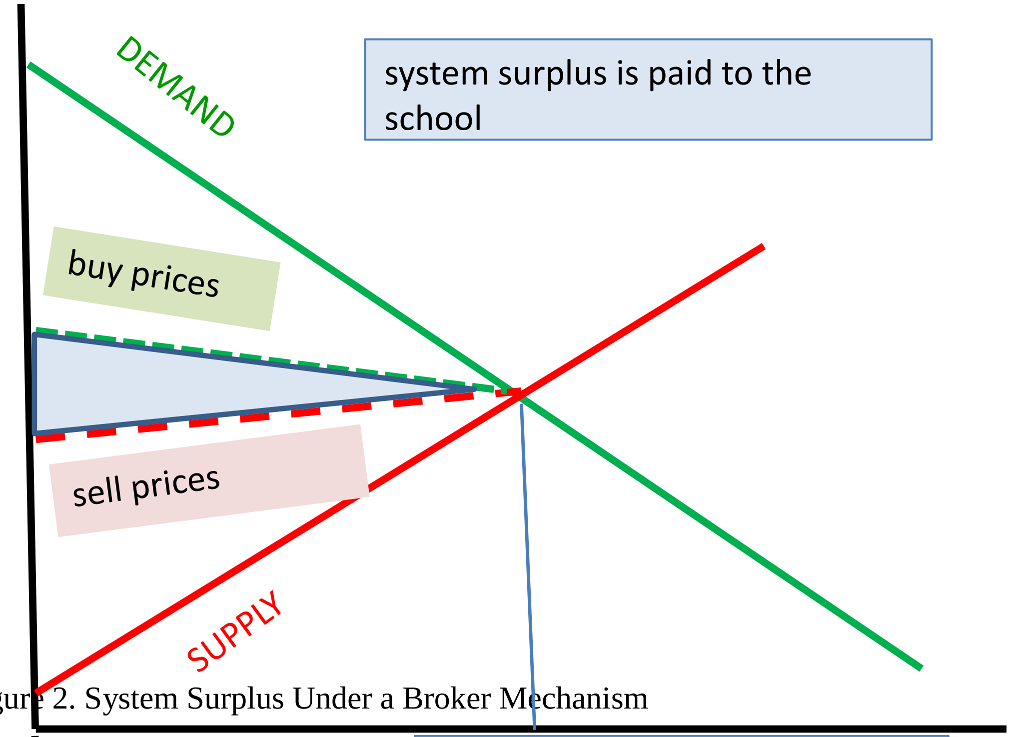


Figure 2. System Surplus Under a Broker Mechanism

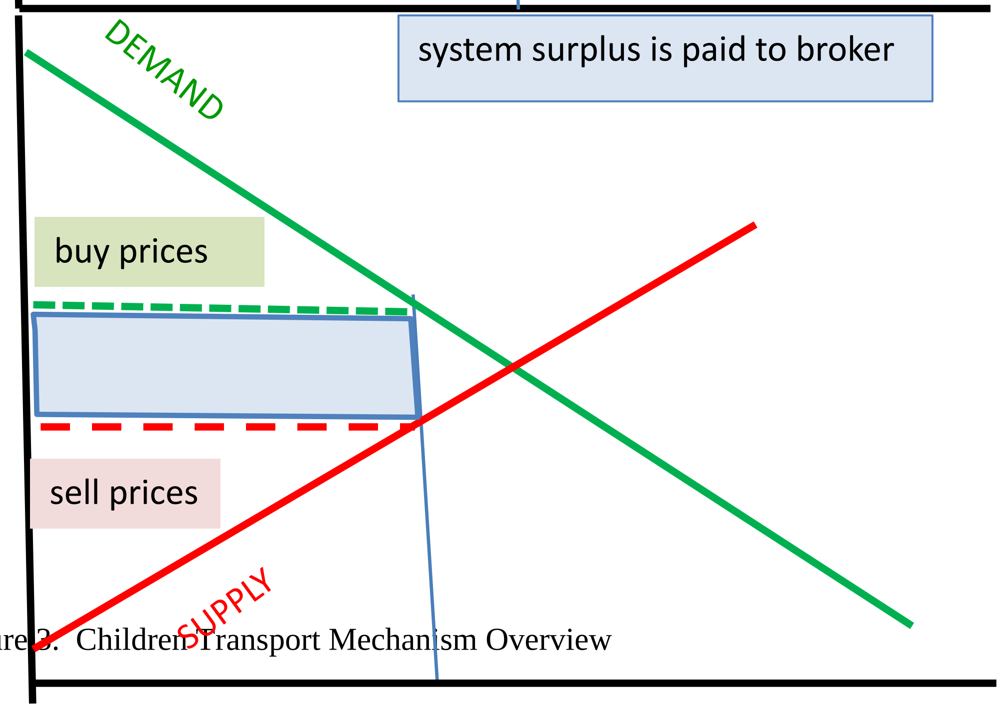
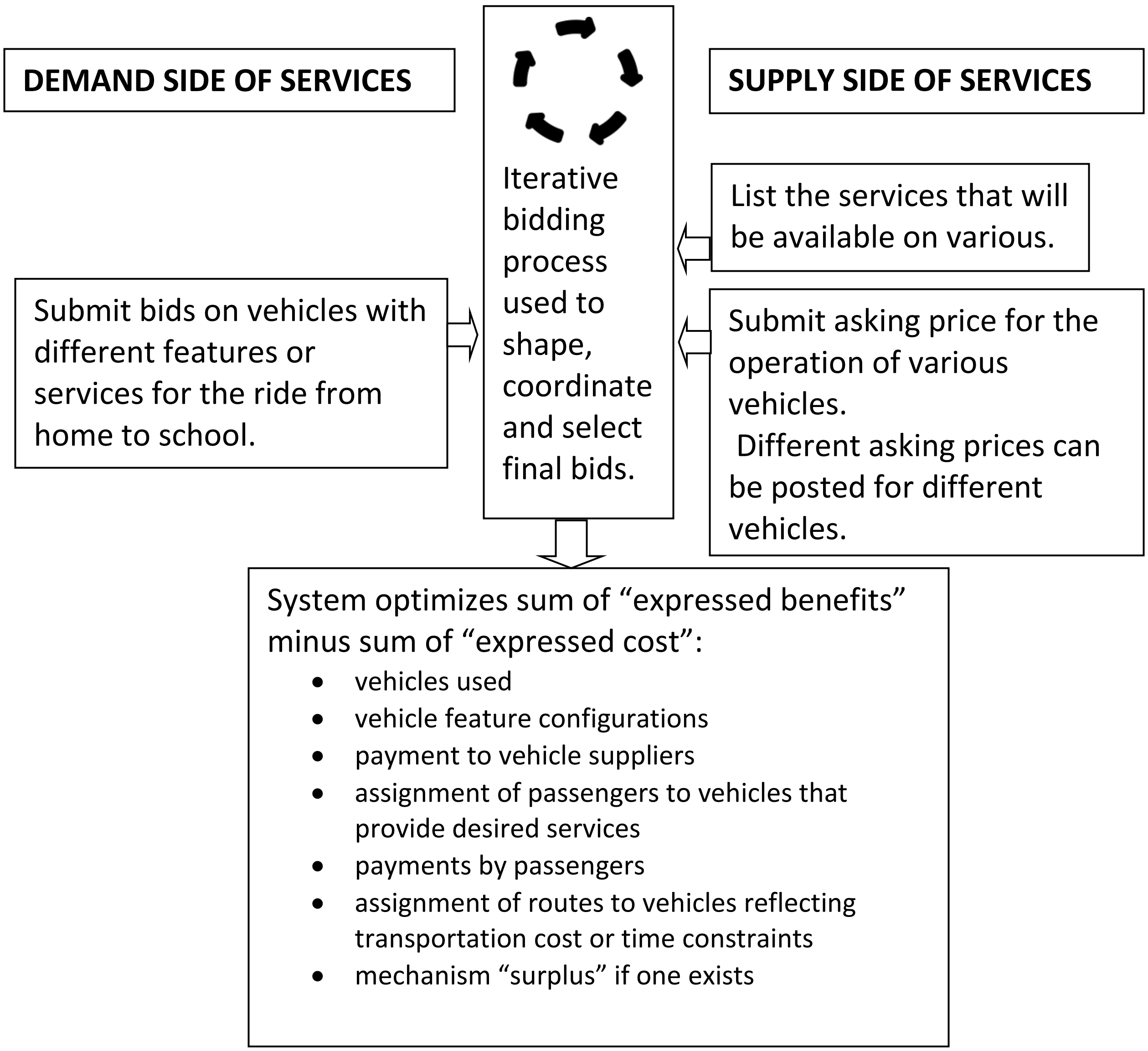


Figure 3. Children Transport Mechanism Overview


DEMAND SIDE OF SERVICES
SUPPLY SIDE OF SERVICES
Iterative bidding process used to shape, coordinate and select final bids.
List the services that will be available on various.
Submit bids on vehicles with different features or services for the ride from home to school.
Submit asking price for the operation of various vehicles.
Different asking prices can be posted for different vehicles.
System optimizes sum of “expressed benefits” minus sum of “expressed cost”:
vehicles used
vehicle feature configurations
payment to vehicle suppliers
assignment of passengers to vehicles that provide desired services
payments by passengers
assignment of routes to vehicles reflecting transportation cost or time constraints
mechanism “surplus” if one exists

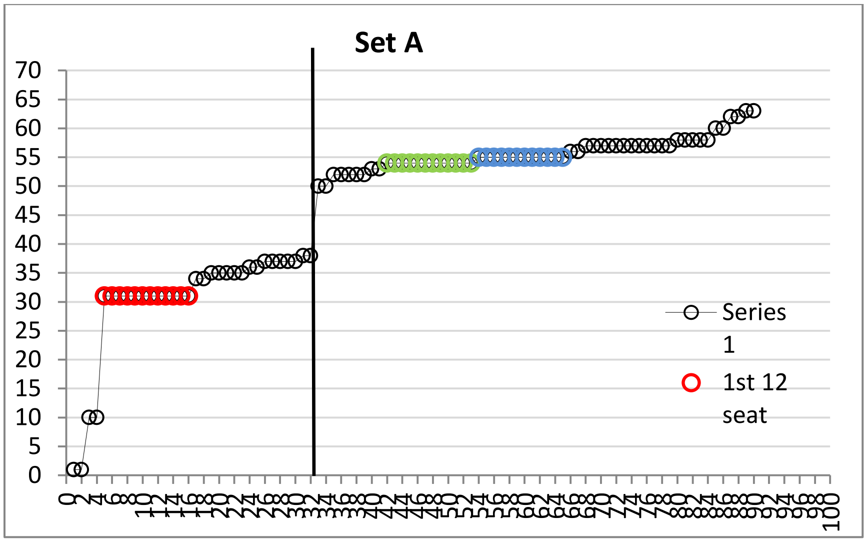


Figure 4. Parameter Set A: One Price Equilibria External Margin 50 and Internal Margin 38

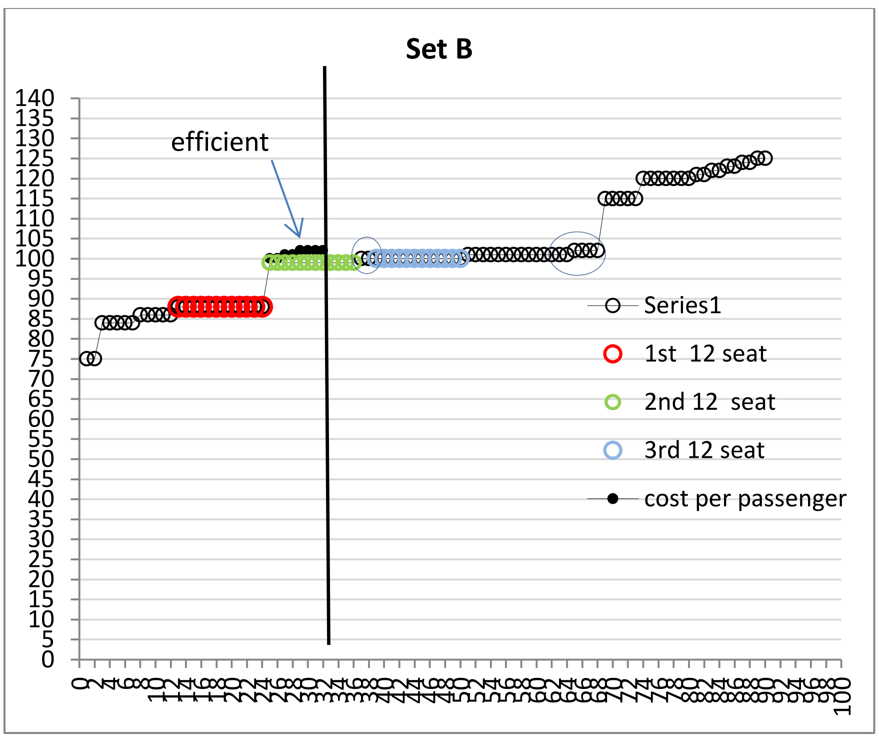


Figure 5. Parameter Set B: One Price Per Passenger Equilibria External Margin 102 and Internal Margin 99 and Partial Fill and thus Zero Marginal Cost for a Passenger

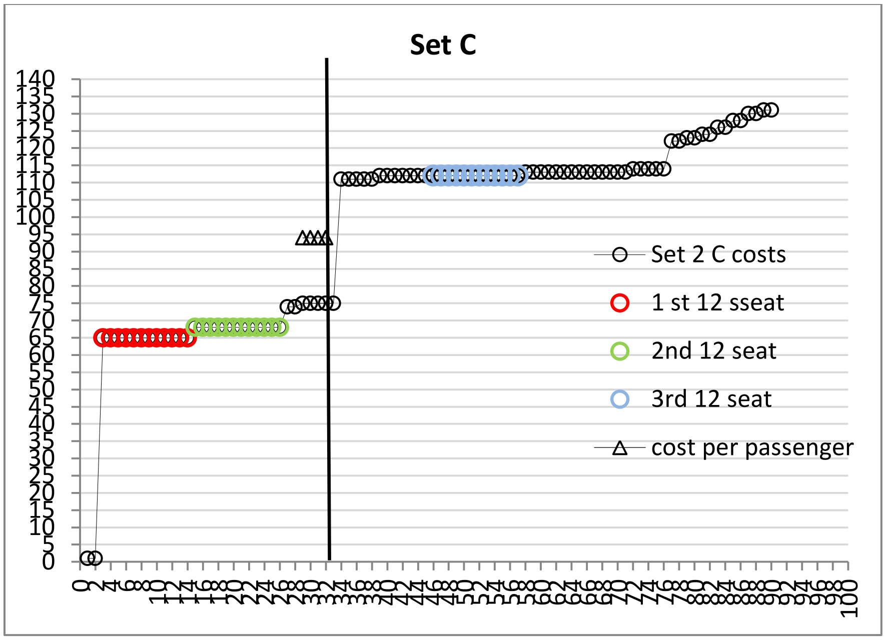


Figure 6: Parameter Set C: Equilibrium Price Per Passenger External Margin 111 and Internal Margin 95, Internal Marginal Cost per Seat 75 and Zero Marginal cost for a Passenger

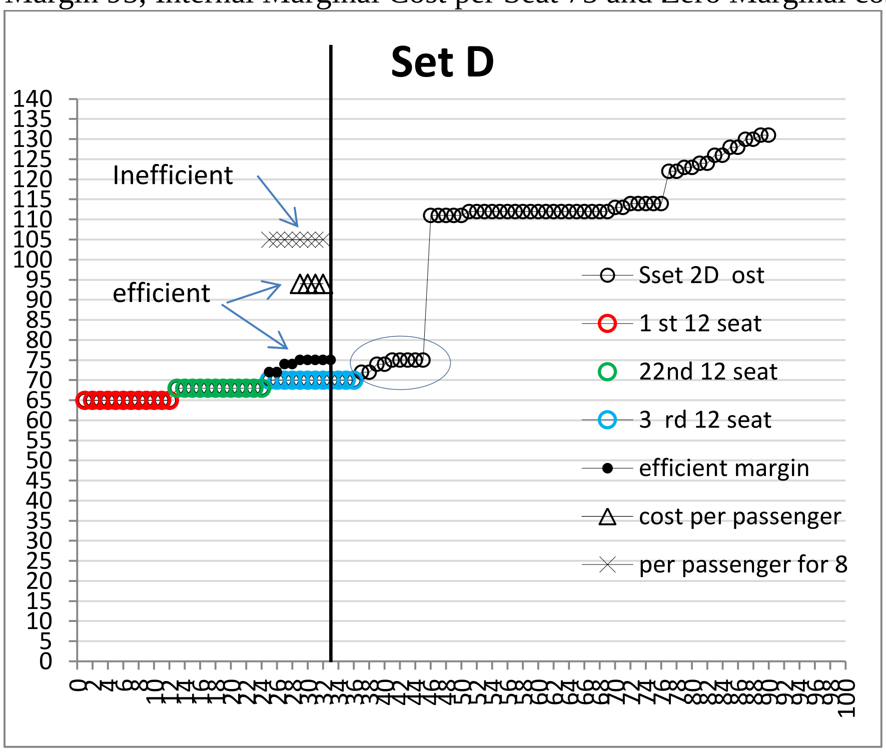
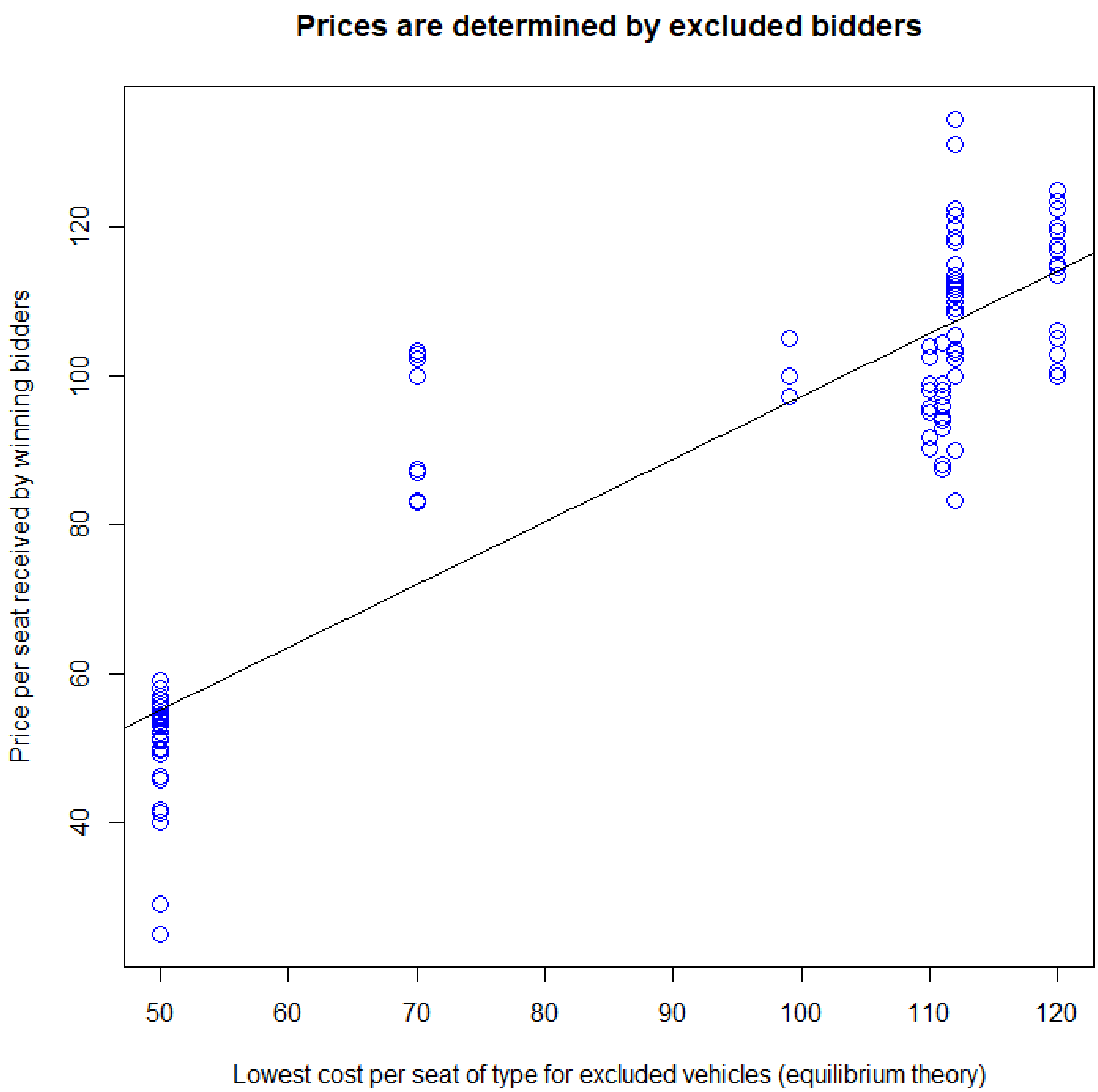


Figure 7: Parameter Set D: Equilibrium Price External Margin per Passenger 111, Internal Margin per Passenger 94; Internal Margin Cost per Seat 75 (Partial Fill thus Zero Marginal Cost for a Passenger).

Figure 8: Prices by Type Determined by Lowest Cost Excluded Bidder of Type



Variable	Coefficient	Std. Error
Price per seat	0.9896	0.0394
Intercept	2.0744	3.6484
R squared	0.833	

Table 1: Total Cost and Cost per Seat by Vehicle Size, Parameter Set and Experimental Session

Set A

# seats		#311 VID	cost	Cost/ seat	#312 VID	cost	Cost/ seat	#313 VID	cost	Cost/ seat	#314 VID	cost	Cost/ seat
2	cab	0	20	10	4	2	1	8	72	36	14	76	38
2	cab	1	112	56	5	68	34	9	106	53	15	100	50
2	cab	2	120	60	6	124	62	10	126	63			
5	MB	3	185	37	7	260	52	11	175	35	16	290	58
12	bus							12	648	54	17	372	31
12	bus							13	660	55	18	684	57

Set B

# seats		#311 VID	cost	Cost/ seat	#312 VID	cost	Cost/ seat	#313 VID	cost	Cost/ seat	#314 VID	cost	Cost/ seat
2	cab	0	200	100	4	202	101	8	204	102	14	150	75
2	cab	1	240	120	5	244	122	9	248	124	15	204	102
2	cab	2	242	121	6	246	123	10	250	125			
5	MB	3	420	84	7	430	86	11	575	115	16	600	120
12	bus							12	1056	88	17	1188	99
12	bus							13	1212	101	18	1200	100

Set C

# seats		#311 VID	cost	Cost/ seat	#312 VID	cost	Cost/ seat	#313 VID	cost	Cost/ seat	#314 VID	cost	Cost/ seat
2	cab	0	2	1	4	148	74	8	226	113	14	260	130
2	cab	1	244	122	5	224	112	9	252	126	15	262	131
2	cab	2	246	123	6	248	124	10	256	128			
5	MB	3	555	111	7	375	75	11	570	114	16	560	112
12	bus							12	816	68	17	780	65
12	bus							13	1356	113	18	1344	112

Set D

# seats		#311 VID	cost	Cost/ seat	#312 VID	cost	Cost/ seat	#313 VID	cost	Cost/ seat	#314 VID	cost	Cost/ seat
2	cab	0	144	72	4	148	74	8	226	113	14	260	130
2	cab	1	244	122	5	224	112	9	252	126	15	262	131
2	cab	2	246	123	6	248	124	10	256	128			
5	MB	3	555	111	7	375	75	11	570	114	16	560	112
12	bus							12	816	68	17	780	65
12	bus							13	840	70	18	1344	112

Table 2. Optimal Allocations by Parameter Set: A, B, C and D

Set A	**Optimal**			
PIC	vid#	Capacity	cost	CostPS
311	1	2	20	10
313	12	5	175	35
314	15	2	76	38
314	18	12	372	31
311	4	5	185	37
312	5	2	2	1
312	6	2	68	34
313	9	2	72	36
		Total 32	Total 970	

Set B	**Optimal**			
PIC	vid#	Capacity	cost	CostPS
311	1	2	200	100
313	13	12	1056	88
314	15	2	150	75
314	16	2	204	102
311	4	5	420	84
312	5	2	202	101
312	8	5	430	86
313	9	2	204	102
		Total 32	Total 2866	

Set C	**Optimal**			
PIC	vid#	Capacity	Cost	CostPS
311	1	2	2	1
313	13	12	816	68
314	18	12	780	65
312	5	2	148	74
312	8	5	375	75
		Total 33	Total 2121	

Set D	**Optimal**			
PIC	vid#	Capacity	cost	CostPS
311	1	2	144	72
313	13	12	816	68
314	18	12	780	65
312	5	2	148	74
312	8	5	375	75
		Total 33	Total 2263	

Table 3. Numerical Simulations of Mechanism Outcomes Under the Assumption of Best Reply Behavior

Comparison of aggregate winner cost with efficient supply:
three simulations of each parameter set

	Simulations Set A			Simulations Set B			Simulations Set C			Simulations Set D		
	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
Winner Cost	970	1002	970	2866	2866	2866	2121	2196	2121	2263	2263	2263
Optimal Cost	970	970	970	2866	2866	2866	2121	2121	2121	2263	2263	2263
error	0	32	0	0	0	0	0	75	0	0	0	0

Table 4. Efficiency in Experimental Tests

Supply Efficiency Loss = [cost of units delivered – minimum possible cost of delivering 32]/minimum possible					
Period	20170413	20170418	20170419	20170420	20170424
1(practice)	0.00%	4.54%	15.15%	22.99%	39.59%
2 Set A	0.00%	8.25%	0.00%	3.30%	0.00%
3 Set B	0.00%	1.54%	1.54%	4.68%	0.00%
4 Set C	0.00%	0.00%	0.00%	3.68%	0.00%
5 Set D	0.00%	0.00%	3.45%	4.95%	0.00%

Table 5. Bid Price of Excluded Bidder of a Type and Bid of Included Bidder; All Parameter Sets

	Type Capacity	Excluded bidder price	Average price of included bidders
Set A	2	50	52.5
	5	52	48.4
	12	54	51.1
Set B	2	120	114.3
	5	110	97
	12	99	99.9
Set B	2	112	113
	5	111	94.2
	12	112	100.9
Set B	2	112	116.2
	5	111	96.1
	12	70	95.2

INSTRUCTION APPENDIX

version
201704410

Transport provision auction

- overview
- cost forms for testing exercises
- bidding screens
- rules
- issues and comments

OVERVIEW OF EXPERIMENT

You are offering to provide a transportation service at a price (your bid). Providing the service costs you money. You make money by selling the service for more than it costs.

Your cost & profit page/link/handout gives your vehicles and their costs.

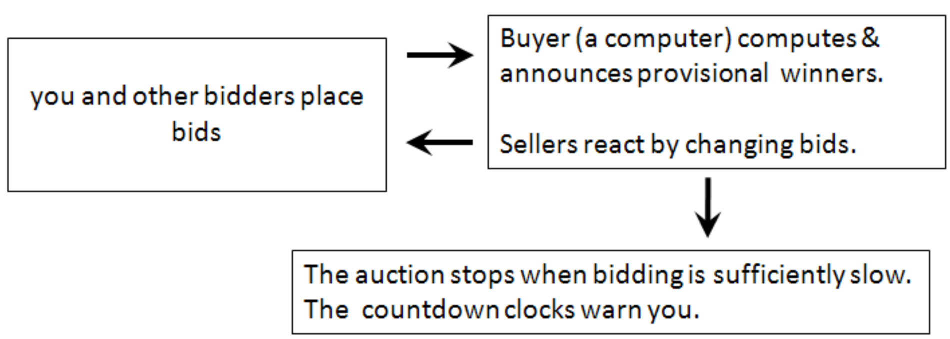
These instructions tell you:

- how to sell the service of your vehicles; how you submit bids in the auction and determine the price.
- the rules of the auction.
- how the auction works and how it ends.

A buyer is conducting an auction to buy transportation services that meet a fixed set of transportation needs. Successful sellers will be those who offer the appropriate services at the lowest cost to the buyer. From your point of view the process is as follows:

You incur cost only for the exact services you sell. Study your cost.
If you sell for less than your cost you lose money.

The market is continuous (open) bidding through the computer.



Your costs: example of incentive and record form for multi period testing exercises

Period/round COST	Your ID	Vehicle ID	Vehicle seats	Your cost		
	Your PIC	Vehicle ID	capacity	total cost	cost per seat	
		123	3	3000	1000	
		456	3	3300	1100	
		78	10	15000	1500	
		99	22	22000	1000	

PROFIT RECORD						
	period	Vehicle ID	capacity	price	cost	Profit Price-Cost
	1	123			3000	
		45336			3300	
Total profit for period						

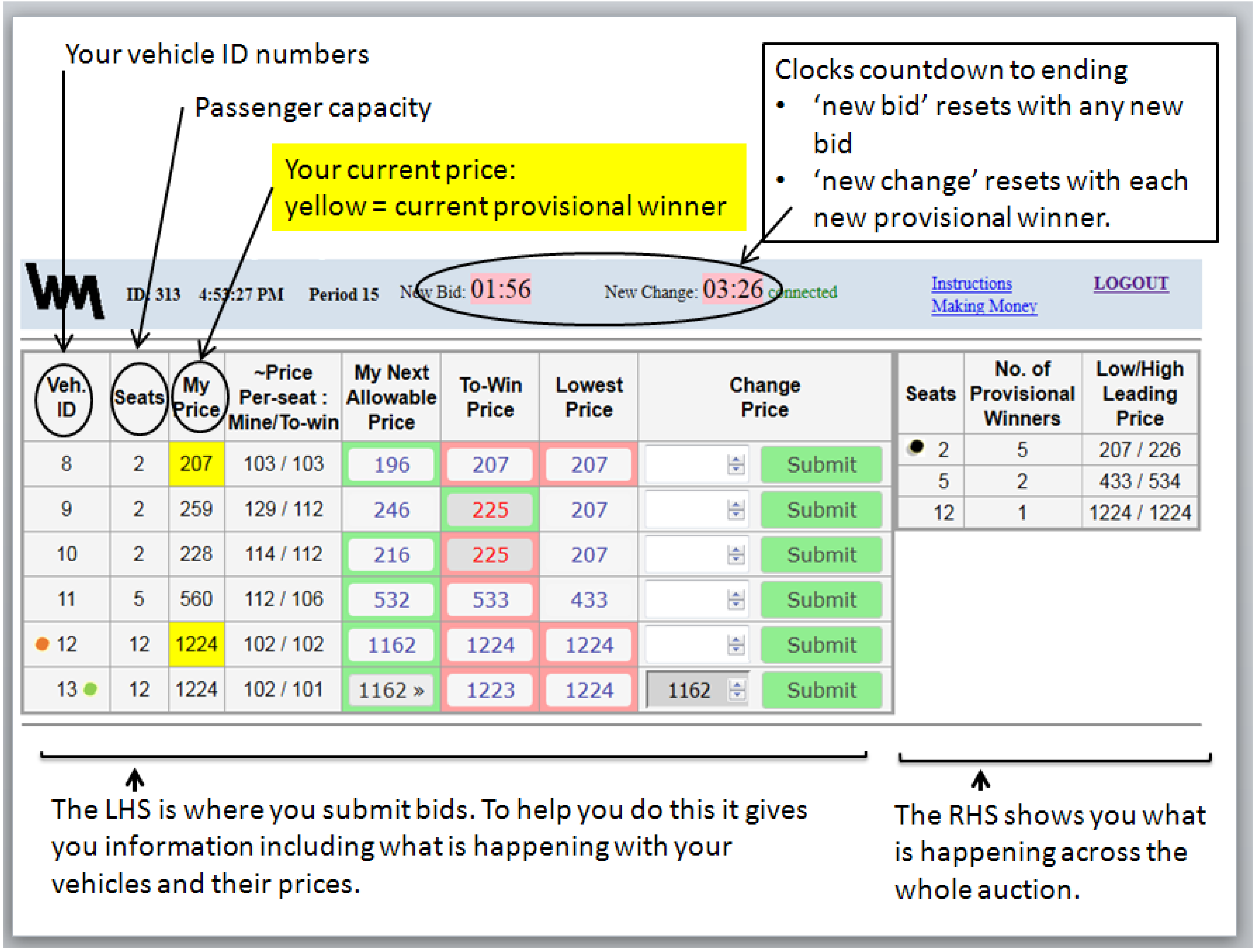
You have several vehicles to use. For e.g. here you have four vehicles: 123, 456, 78 and 99. Each has a different passenger capacity and cost to you if used (i.e. cost to you if your bid is successful).

Profit = auction price – vehicle cost

<u>Price is determined in auction</u>

If your bid for a vehicle wins the auction the price paid to you for your vehicle's use is the amount you bid.

- A bid less than the cost will result in a loss to you.
- High bids might lose in the competition.



Veh. ID	Seats	My Price	~Price Per-seat : Mine/To-win	My Next Allowable Price	To-Win Price	Lowest Price	Change Price	
8	2	207	103 / 103	196	207	207		Submit
9	2	259	129 / 112	246	225	207		Submit
10	2	228	114 / 112	216	225	207		Submit
11	5	560	112 / 106	532	533	433		Submit
12	12	1224	102 / 102	1162	1224	1224		Submit
13	12	1224	102 / 101	1162 »	1223	1224	1162	Submit

Seats	No. of Provisional Winners	Low/High Leading Price
2	5	207 / 226
5	2	433 / 534
12	1	1224 / 1224

The price your bid for a vehicle must be a certain percentage (or more) below your current price for that vehicle. ‘My next allowable price’ is that amount. You must bid your next allowable price or less. This rule ensures the auction is timely and orderly.

The ‘to-win price’ shows the price at which a vehicle of the same capacity would become a provisional winner in the auction. Your next allowable price may be less than the to win price.

The ‘lowest price’ show the lowest price in the auction for a vehicle of that capacity. Your next allowable price may be less than the lowest price.

The price you must bid to become a provisional winner (the lower of your ‘next allowable price’ and the ‘to win’ price) will be active and appear in a green box. Red boxes are de-active as they violate the increment requirement.

ID: 313 4:53:27 PM Period 15 New Bid: 01:56 New Change: 03:26 connected Instructions Making Money LOGOUT

Veh. ID	Seats	My Price	~Price Per-seat : Mine/To-win	My Next Allowable Price	To-Win Price	Lowest Price	Change Price	
8	2	207	103 / 103	196	207	207		Submit
9	2	259	129 / 112	246	225	207		Submit
10	2	228	114 / 112	216	225	207		Submit
11	5	560	112 / 106	532	533	433		Submit
● 12	12	1224	102 / 102	1162	1224	1224		Submit
13 ●	12	1224	102 / 101	1162 »	1223	1224	1162	Submit

Seats	No. of Provisional Winners	Low/High Leading Price
● 2	5	207 / 226
5	2	433 / 534
12	1	1224 / 1224

You can keep track of what is happening across the auction in the RHS:

Low/High leading price = the price range of provisional winners at each seat capacity

No. of provisional winners = number of vehicles currently winning at each capacity

A black dot tells you a new bid was submitted for a vehicle of this capacity

ID: 313 4:53:27 PM Period 15 New Bid: 01:56 New Change: 03:26 connected

Instructions
Making Money
LOGOUT

Veh. ID	Seats	My Price	~Price Per-seat : Mine/To-win	My Next Allowable Price	To-Win Price	Lowest Price	Change Price	
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13	12	1224	102 / 101	1162	1223	1224	1162	Submit

Seats	No. of Provisional Winners	Low/High Leading Price
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12	1	1224 / 1224

You submit bids in the LHS: ↑

Click on the price you wish to submit (remember a price in a red box is not allowed).

You can adjust the price manually using the arrows in the change price field, but to be accepted it must remain at or below your next allowable bid.

BIDDING RULES

- When the auction ends provisional winners become winners.
- In order to supply the total demand, multiple vehicles will be provisional winners. Bid price determines priority for choosing provisional winners when vehicles have the same capacity but multiple vehicles with different prices could be provisional winners. If your bid is not the low bid it could still be a provisional winner if more than one vehicle of this capacity is provisionally winning.
- The price of a provisionally winning bid can be only lowered and if lowered it must meet the increment requirement.
- Low bid is time stamped and in case of a tie earlier bid time dictates priority.

HOW THIS WORKS

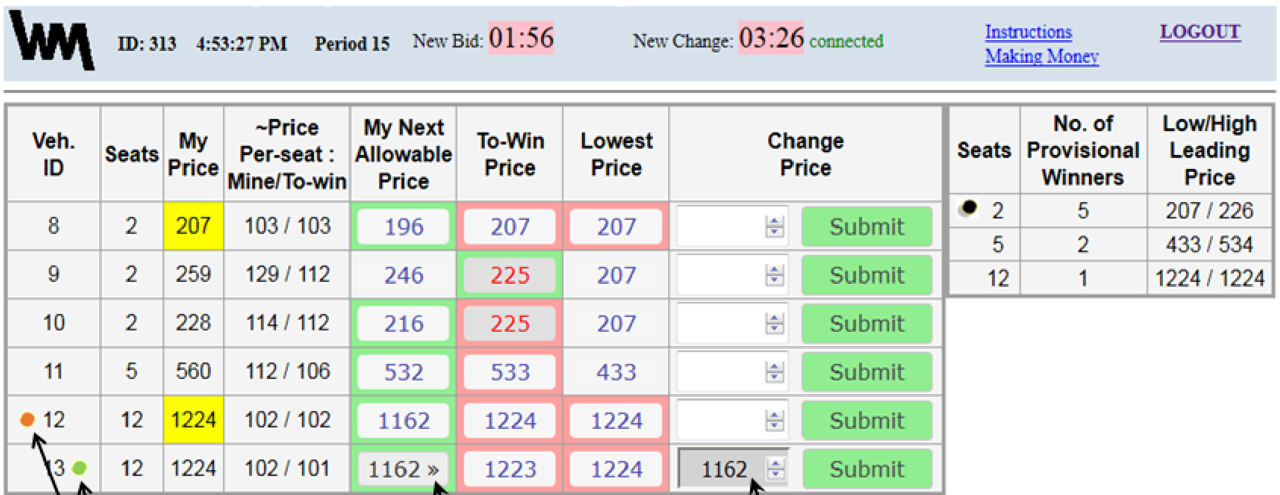
The auction continuously searches for new sets of potentially winning bids that (i) supply all of the services demanded and (ii) fit together at a total cost of winning bid prices less than the current set of provisionally winning bid prices.

The "to-win" price tells you what you need to do to "fit" in a new set of provisional winners while lowering the total cost of the set sufficiently to become provisionally winning (and thus the new group becomes the new provisional winners).

Notice that your "to-win" price depends on what others bid. If others bid low then your price need not be so low (your to-win price will go up) because they are absorbing the cost of beating the current provisional winning set. Or, if your bid is high then the others must bid low in order to supply the needed transportation cheaper and become new provisional winners. Thus, a tension exists. Others who quote low prices can replace you as a competitor in a provisionally winning set. On the other hand, if others quote high prices you must do more work (a low to-win price for you) if the existing provisionally winning set is to be replaced.

Since the auction works by searching for the combination of vehicle capacities and prices that fit together to meet the required transportation services at minimum total cost, a new provisionally winning bid can change the combination by bringing in other bids as provisional winners and causing a number of previous provisional winners to become provisional non-winners.

The system helps you can see the impact of making a new bid for one of your vehicles on your bids for other vehicles in the system:



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Seats	No. of Provisional Winners	Low/High Leading Price
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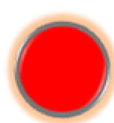
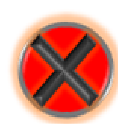
5	2	433 / 534
12	1	1224 / 1224

Place your mouse cursor on a price. It will appear in the submit price area.
Green dot indicates bids that will be drawn into the provisional winners.
Orange dots indicate bids that will be removed from the provisional winners.

ENDING RULES AND CLOCKS

- The auction ending is determined by a countdown clock. The new bid clock resets with each new bid. The auction ends if the new bid clock reaches zero.
- **There is no advantage to delay bids.** When you submit the clocks will reset. Your delay will simply give others more time to bid.
- **Last moment bid submissions are discouraged. Strategic delays only prolong the auction.** The auction enters a "closing period" when only YYY seconds [to be announced before auction begins] remain on the new bid clock. Any bid submitted during the "closing period" will reset the new bid clock and the auction will continue as before. However, a bidder who places a bid during any closing period will not be able to do it again. For such a bidder the bid submit button will not be active after the new bid clock descends to YYY.
- Thus, the auction effectively ends when the new bid clock descends to YYY and the closing period begins . Bidders have no incentive to bid as the clock descents further but the auction remains open for a short period in case a bidder accidently failed to submit a bid before the closing period begins. Remember there is no advantage to you to delay bids since the clock resets, you will only provide others with more time to bid.

- Blinking lights "closing period approach"   "in closing period"

The End