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COMPETITION FOR VERSUS ON THE RAILS: A LABORATORY EXPERIMENT*

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European countries and Japan are contemplating more competition in passenger rail service. In the Netherlands, the Ministry of Transport was assigned responsibility for making a recommendation to Parliament for choosing between competition for the rails and competition on the rails. The Ministry commissioned the experiments reported here to acquire better understanding of the properties of the alternative policies. Competition on the rails involves allocation of rights to use station and time-slot routes by price bids in a combinatorial auction. Competition for the rails involves allocation of rights to regional monopolies by fare-structure bids for supplying a prespecified minimum schedule.

1. INTRODUCTION

Several European countries and Japan are in various stages of privatization of passenger rail services and/or the introduction of more competition in the market for these services. In many countries, these services were formerly supplied by vertically integrated state monopolies or strongly regulated private monopolies. For example, in the Netherlands the passenger service has been in the hands of a monopoly (“De Nederlandse Spoorwegen” or “NS”) since 1937. This monopoly involved both the infrastructure and its various uses. It was created in order to better coordinate the rail services that had previously been run by small companies, each with a limited number of routes. In order to keep control over this monopoly, the Dutch government became the sole shareholder and introduced severe regulation. The NS became

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very dependent on the government for financial support and was forced to adhere to strict government policy, both with respect to routing and pricing.

A common pattern in Europe over the past decade has been to adopt partial privatization in which a state monopoly retains ownership of the infrastructure whereas private firm(s) acquire rights to use it. This process has been furthered by a directive from the Commission of the European Communities (1991) requiring member states to separate operations from infrastructure on the books and give international groupings of trains access to their infrastructure. The idea behind this separation is that the infrastructure might involve decreasing average costs and hence natural monopoly arguments for government intervention might be valid. In contrast, operation of rail transportation services does not ordinarily involve decreasing average costs.

The course of partial privatization has varied between countries and over time within countries. In the Netherlands, the first stage was to formally end NS's responsibility for development and maintenance of the infrastructure.[2] NS retained the rights to use the infrastructure (hereafter, the ''rails'') as a regulated private monopoly; however, regulation (and subsidization) have been decreasing since 1991. In this way, a deregulated private monopoly is being created. The next stage will involve introduction of competition. In 1997/1998, two possibilities were considered: either competition for the rights to regional monopolies or competition on location and time slot routes in the network; that is, either competition *for* or competition *on* the rails.

The Netherlands Ministry of Transport, Public Works, and Water Management (hereafter, the Ministry) was assigned responsibility for making a recommendation to the Netherlands Parliament for choosing between competition *for* and *on* the rails. In developing its policy recommendations, the Ministry had three objectives and a vaguely articulated ordering of their relative importance. The most central objective was the provision of ''passenger service,'' which meant a fairly dense schedule of trains running on the many routes and time slots in the network. A second objective was the promise of ''low fares,'' but not fares so low as to require a continuation of government subsidies. A third, somewhat tenuous objective, was the possible use of rail transportation to raise revenue for the public treasury.

Based on these objectives, the Ministry narrowed its consideration to two alternative policies: (1) a passenger-fare structure, low-bid auction for allocation of regional monopolies in competition *for* the rails; and (2) a revenue-generating, high-bid auction for allocation of rights in competition *on* the rails.[3] The Ministry commissioned the experiments reported in this article in order to acquire better understanding of the properties of these two alternative policies. Thus, this article is a case study in how experimental economics can be used in formulating public policy recommendations. By analogy with accepted procedures for developing new airplane designs, our laboratory treatments can be viewed as ''wind-tunnel'' experiments intended to detect unforeseen problems and design–objective tradeoffs before

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[2] In fact, the NS still participates in the government organization now in charge of the infrastructure. However, the NS and this organization are already separated to a higher degree than currently prescribed by the EU.

[3] It is not quite clear why the objectives led to precisely these two alternatives. However, it was clear that the Ministry was determined about the major elements in these alternatives. We will reflect below on the Ministry's considerations when choosing these alternatives.

incurring the costs of full-scale field trials. Because this research is of the wind-tunnel type, it has its limitations from a purely academic point of view. The main limitation is the absence of a ‘‘crossed design’’ that would reveal the separate effects of distinct components of alternative policies.

In evaluating data from our wind-tunnel experiments, we implemented the passenger service and low-fares objectives by comparing the performance of the alternative policy treatments to two baseline allocations that maximize consumer surplus. One such baseline allocation is the fully efficient allocation with zero prices. Because the fully efficient allocation would not be feasible for unsubsidized private firms, we also consider the baseline allocation that maximizes consumer surplus subject to the constraint that passenger-fare revenue is greater than or equal to the fixed and variable costs of running trains on the network.

When commissioning the experiments, the Ministry had certain ideas about the content of policies for implementing competition *for* and *on* the rails. These ideas determined the structure of our experiments to a large extent. Here, we give a brief overview of these ideas. More details are given below. In competition *for* the rails, the railway network would be split into regions. Operators would bid in an auction for the monopoly rights to a complete region for a limited time. The government would provide a minimum schedule that would have to be run in a region. In the auction used for allocating rights, operators would bid the passenger-ticket prices (or fares) to be charged. The operator willing to charge the lowest price structure in each region would be given the rights. Those prices would have to be charged for all transport, not just on the minimum schedule. In competition *on* the rails, the government would distinguish a large number of individual route/time slot marketable goods (e.g., Rotterdam–Amsterdam at 7:10 a.m.). The rights to route/time slots would be allocated in a combinatorial auction. Revenue would go to the government and there would be no minimum schedule.

Note that there are important differences between these two plans for introducing competition. The most important differences are in the procedures for allocating rights and in the minimum schedule that is used in competition *for* the rails but not in competition *on* the rails. These differences must be dealt with in a way that makes a straightforward comparison possible. How our experimental design incorporates these features of the alternative plans is discussed below.

The Ministry’s formulation of the two policy alternatives apparently reflected the following considerations. Use of a revenue-raising auction to allocate regional monopoly rights in competition *for* the rails was ruled out because, in the absence of regulation, it would leave the regional monopolists free to implement monopoly pricing and relatively little passenger service. Requiring winning bidders to provide (at least) the prespecified minimum schedules and to charge no more than the fares they bid would put a floor under the level of passenger service and a ceiling on fares that would be charged by the regional monopolists operating in the competition *for* the rails environment. Furthermore, the minimum schedule would provide quantity weights for use in constructing an index of proposed fares to be used in determining which bids were winning (low) bids. In contrast, imposition of a minimum schedule on bidders in competition *on* the rails was considered unnecessary because firms would be unlikely to bid for route and time slots that they did not intend to use.

Furthermore, competition among firms operating in the competition *on* the rails environment was assumed to constrain attempts at monopoly pricing.

Previous experiments have been done studying mechanisms for allocating rights to use the rails (e.g., Brewer, 1999, 2002; Brewer and Plott, 1996; Isacsson and Nilsson, 2001; Nilsson, 1999, 2002). These studies are discussed in the following section. They are primarily concerned with allocation of rights to use the infrastructure. Because we are mainly concerned with studying the implications of choosing between competition *for* and competition *on* the rails, our experiments differ significantly from previous ones. The most notable difference is that we study both the allocation of rights and the scheduling and pricing of trains. This is done at the cost of paying less attention to the question of designing an optimal auction to use for allocating the rights, which was the main focus of previous studies. Thus, the research programs are complementary since their focus is on different aspects of the rail network privatization problem.

The rest of the article proceeds as follows. Section 2 describes properties of the Dutch railway network that should be included in the experimental environment and discusses previous experimental work on similar networks. Section 3 presents the network model used in the experiments. Section 4 describes the experimental route scheduling and pricing tasks and the experimental design and procedures, including the combinatorial auction used to allocate routes in competition on the rails. Section 5 reports analysis of data from the experiments. Section 6 contains concluding remarks.

2. THE RAIL NETWORK ENVIRONMENT

2.1. *Characteristics of the Dutch Railway Network.* The following six points describe the important characteristics of the Dutch railway network that should be incorporated into an experimental design:

1. The infrastructure is owned and maintained by the government.
2. Each combination of a route and time slot can be seen as a marketable good. There are substitutabilities and complementarities in demand for these transportation goods.
3. The cost structure includes fixed and variable costs. The fixed costs reflect the leasing (or depreciation) of trains. The variable costs can include fees for use of the infrastructure.
4. Marginal costs for additional passengers are 0, with ‘‘spikes’’ at transportation levels where additional cars have to be added to a train. The marginal cost is infinite where the maximum train length is reached.
5. Operators know the demand structure.
6. The demand for transportation is:

   - negatively related to the price of transportation;
   - negatively related to travel time;
   - higher if there are connecting trains (*station complementarity*);
   - lower if there are other trains on the same routes in adjacent time slots (*time-slot substitutability*);
   - higher in some time slots than in others.

2.2. *Previous Experimental Studies.* There have been previous experimental studies with natural gas networks (McCabe et al., 1989; Rassenti et al., 1994), electric power networks (Rassenti and Smith, 1998; Zimmerman et al., 1999), and water supply networks (Dinar et al., 1998). These authors have successfully incorporated the essential features of their network environments into experimental laboratory models. Previous experimental studies of railway networks used the following structure. A "point of departure" is a set of possible trains that could run on the rails. Some of these trains are in conflict: they cannot simultaneously be allocated. Participants in the experiment represent operators. They are given redemption values for the various trains. If they are allocated the rights to a train, it is automatically assumed that the train will be run and operators earn the redemption value attributed to that train. The objective of previous studies of rail networks has generally been to study how various auction mechanisms perform in dealing with route conflicts between trains when efficiently allocating the rights.

The binary conflict ascending price (BICAP) procedure introduced by Brewer and Plott (1996) admits multiple rounds of bidding. The standing bids at any round are the ones that yield maximum revenue from amongst all subsets of bids that contain no conflicting routes. In their experiments, the BICAP mechanism produced highly efficient allocations of rights. Brewer (1999) added a secondary computerized market to support agents in finding feasible, revenue-increasing route assignments. His initial experiments provide support for the effectiveness of this smart market. Brewer (2002) discusses extensions of the mechanism applications to network environments with externalities and public goods. These extensions make it possible to incorporate the revenue implications of station complementarity and time-slot substitutability in the redemption values.

In a similar setting, Nilsson (1999) reports experiments with a multiround Vickrey-type auction of routes. The auction mechanism imposes noncollision feasibility constraints. The pricing rule charges a winning bidder the highest aggregate value of all bids that his combinatorial bid displaces. The reported experiments generated allocations of rights that were 90–100 percent efficient. Isacsson and Nilsson (2001) extend this experimental research to include four types of auction markets constructed by crossing first-price and second-price auction pricing rules with one-shot (or sealed-bid) and ascending-price (or multiple-round) bidding procedures.

2.3. *Experimental Design Differences.* The structure of the previous experiments was well suited for the problems addressed in those studies. That structure allows one to capture some, but not all, of the characteristics of the Dutch railway network described above. The infrastructure is given. Costs and market synergies (substitutability and complementarity) can be incorporated in the induced redemption values, as can peak and off-peak demand. However, the nonzero own- and cross-price elasticity of demand for travel on route/time slots and other characteristics related to prices are not captured in this structure. In addition, note that the synergies are imposed if one applies them in this way. A different matter is whether operators are capable of actually taking account of these synergies when scheduling trains. For our study, the coordination problem may be very important because the coordination difficulties may be different in competition *on* and *for* the rails.

Therefore, in our experiments, we have decided to split the allocation of rights from the scheduling and pricing of trains. We believe that the present article—though from the outset it is a wind-tunnel experiment where the treatments were determined by the questions raised by the ministry—is the first to report experiments that involve both allocation and scheduling and also the first to experimentally compare competition *for* and competition *on* the rails.[4] In introducing these features of the rail network environment into our experiments, we have simplified other aspects of the network design. First, we have kept the auction used to allocate rights as simple as possible, keeping in mind the tradeoff between simplicity and efficiency. We focused on the comparability of the auctions in *for* and *on* the rails (in terms of number of rounds, stopping rules, etc.) and on some basic characteristics that should support efficiency of the auction.[5] Nevertheless, as will become clear below, differences between our treatments remain that go beyond the matter of just competition *on* versus competition *for* the rails. In particular, there is an important difference in the way the auctions are organized. Second, we assume a common values structure: The demand structure and fixed and variable costs of running trains are the same for all operators. This is the appropriate use of induced valuation for the purposes of our experiments. With separation of ownership of the infrastructure from operations, there is no reason for firms to have distinct fixed and variable costs of running trains. Most likely, different operators would all lease their trains from the same leasing firms, at the same prices. Furthermore, all firms bidding for rights would have potential access to the same station/time slots and thus face the same network demand structure. Differences between firms in the actual costs of operating trains, and in the actual realized passenger demands, would result from differential performance in scheduling trains on the network. But this is the central criterion that we are using to compare the performance of competition *on* with competition *for* the rails. It would not be appropriate for purposes of our research to use induced valuation to *create* differences across firms in demands and costs. In short, though we induce common values, differences across operators are likely to occur in our design. These ‘‘private values’’ are not induced but follow naturally from differences in scheduling performance. The question is whether the more efficient schedulers will be able to outbid the less efficient schedulers in the auction of the rights. The allocation mechanism is used to select the ‘‘best’’ operators.

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[4] As an alternative, one might consider studying the allocation and scheduling in separate experiments. In our view, the joint experiment is essential, however. Subjects will vary in their abilities to schedule efficiently and profitably. It is important to find out whether the allocation procedure can allocate to the ‘‘better’’ producers.

[5] In short, we use a (combinatorial, in case of competition *on* the rails) auction with a high bid (or first-price) pricing rule and ascending-bid, multiple rounds of bidding. We do not experiment with alternative auctions, as do Isacsson and Nilsson (2001). The possibilities for maintaining comparability between the auctions were restricted by the Ministry's demands.

3. A SIMPLE STYLIZED MODEL OF A RAIL NETWORK

Our experimental network is kept as simple as possible to still be able to capture the central features of a rail network. It distinguishes regions, stations, and routes between stations.[6] A "station" is a place travelers can embark and disembark. A "route" provides a link between stations. A "region" is a set of stations where there is a concentration of demand by travelers.

Time is divided into "time slots." The network is double tracked; hence, it is possible to run at most one train in each direction on any route in any time slot. Travel from one station to another within a region takes one time slot. Travel between adjacent stations in different regions also takes one time slot.

The network includes time-slot substitutability and station complementarity. "Time-slot substitutability" means that travel demand for any route between two stations at some specific time is lower if there are other trains on the same route in adjacent time slots. "Station complementarity" means that travel demand for any route between two stations at some specific time is higher if there are connecting trains in adjacent time slots.

3.1. *The Network.* Figure 1 presents the design of the network used in the experiment. In the figure, a line represents a two-way route. The network consists of two regions, A and B. Each region has three stations, 1, 2, and 3. There is one double-tracked route between every adjacent pair of stations. There is one such route between the two regions (route A_3B_3 and B_3A_3). In total, there are seven two-way routes in the network.

Besides these routes between adjacent stations, in both regions there is a direct (double-tracked) route between stations 1 and 3. This allows an express train to travel on the same rails as a local train would travel from 1 to 2 or 2 to 3. It travels twice as fast, however. As a consequence, if there is an express train going from 1 to 3, it is not possible that there is a local train going from 1 to 2 or from 2 to 3 at the same time. Similarly, if there is a local train going from 1 to 2 or a local train going from 2 to 3, it is not possible that there is an express train going from 1 to 3 at the same time. These restrictions hold for both regions and in both directions.

The use of a train in different time slots is constrained by physical restrictions. At any station, in any time slot, a new train can be leased and used (yielding fixed costs and variable costs). A train that was used in any previous time slot can be used again (yielding only variable costs) if it is available at the station it is assumed to depart from. A train is available at a station if it was brought there from its original point of departure using only routes that the operator has the rights to. Finally, for simplicity, we will assume that trains have no binding capacity constraints, which implies that the marginal costs for an additional passenger are zero for any quantity of travel.

Use of the network is divided into five time slots. Except for the restrictions mentioned above (concerning express trains and local trains), any number of trains can travel simultaneously on all routes (in both directions) in any time slot. Only one

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[6] In the experiment, "regions" were called "areas," "stations" were called "nodes," "trains" were called "carts," and "passengers" were called "products."

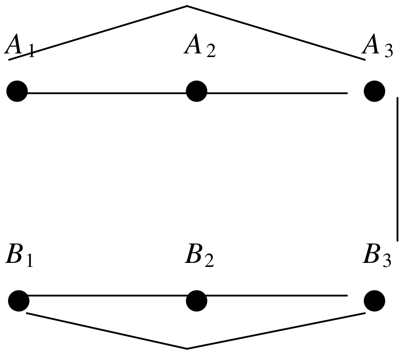

FIGURE 1

THE EXPERIMENTAL NETWORK

train per direction can travel on any single route in any given time slot. The rights to use routes are assigned in the allocation part of an experiment. The allocation procedures take the restrictions into account; thus, if a right to an express train is allocated, no other rights involving that route in that time slot are allocated. As will be explained in Section 4.7, this network is able to capture the main characteristics of the Dutch railway system. Moreover, we believe it is the simplest network that allows us to do so. Finally, it does not favor either competition *on* rails or competition *for* the rail, *a priori*.

3.2. *Demand Structure and Efficient Allocation.* In the experiment, subjects play the role of providers of passenger services. Demand for these services is simulated in a manner that is known to the subjects. This is done as follows. To determine the actual travel on any route, we start with a baseline travel that varies across routes but is the same in time slots $2, \ldots, 5$. In time slot 1, the baseline travel is twice the level in other slots. This represents a peak hour.[7] This baseline travel is adjusted in various ways to determine actual travel on the routes: (a) if no train is run on a route, the actual travel is zero; (b) actual travel on a route decreases with an increase in price for that route; (c) actual travel is lower than baseline travel if another train traveled the same route in the previous time slot or if another train will travel that route in the next time slot; (d) actual travel is higher than baseline travel if there is a connecting train arriving at the departure station (on a different route) in the previous time slot; and (e) actual travel is higher than baseline travel if there is a connecting train leaving from the arrival station (on a different route) in the following time slot.

The following equations are used to determine actual travel, Q_{ij}^t, on the routes from i to j (where $i, j \in \{A_1, A_2, A_3, B_1, B_2, B_3; i \neq j\}$) in time slots $t = 1, 2, \ldots, 5$, if a train is running:

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[7] Note that the baseline demand is assumed to be identical for all subjects. This gives the common value structure referred to above.

$$(1) \qquad Q_{ij}^{t} = \max\left[0, V_{ij}^{t} - p_{ij}^{t} - \alpha\left(Q_{ij}^{t-1} + Q_{ij}^{t+1}\right) + \beta\left(\sum_{ki \in C_{ij}} Q_{ki}^{t-1} + \sum_{jl \in C_{ij}} Q_{jl}^{t+1}\right)\right]$$

where V_{ij}^{t} is the baseline travel, $p_{ij}^{t}(\geq 0)$ denotes the price charged for route ij in time slot t, C_{ij} denotes the set of all routes in the same direction as ij that terminate at i or emanate from j, and $\alpha \in (0,1)$ and $\beta \in (0,1)$ are parameters to be chosen. A route is in the same direction as ij if both this route and ij are a move in the clockwise (or counterclockwise) direction in Figure 1. The term involving α gives time substitutability: There is less travel if the same route is traveled in an adjacent time slot. The term involving β gives station complementarity: There is more travel if there is a connecting train in the same direction in either the previous or the next period.

Given the parameters, one needs to determine the actual travel for any given set of routes being run and prices being charged. Denote by Q the vector containing all Q_{ij}^{t}s. Furthermore, let d_{ij}^{t} be a dummy variable indicating whether or not a train is being run on route ij in time slot t and let D denote the vector of d_{ij}^{t}s (ordered in the same way as Q). Finally, let P denote the vector of prices (p_{ij}^{t}). The set of equations in (1) can then be written as

$$(2) \qquad Q = F[Q(D, P)]$$

For any given D and P, one has the fixed-point problem, $Q = F[Q]$. F is a continuous function. Hence, there is at least one solution to this set of equations if the domain is convex and compact. The domain is clearly convex, and it is compact because of the restrictions, $Q \geq 0$ and $P \geq 0$. Hence, for given D and P, we can determine Q.

Given the parameter values chosen for the demand side, we can determine various allocations to be used as benchmarks in our analyses once the supply-side parameters have been chosen. There are fixed costs, c^1, related to leasing a train and variable costs, c^2, for every route on which a train runs. We will consider three benchmarks: the efficient allocation, the most efficient profitable allocation, and the profit-maximizing allocation. The efficient allocation is the set of routes and prices that maximizes market surplus. We will argue below that this involves prices set to zero and therefore operators making losses. Therefore, for many purposes, the most-efficient profitable allocation is a better benchmark. To find this allocation, we determine the vector D and prices P that maximize total surplus subject to the constraint that revenue is greater than or equal to cost. Finally, the profit-maximizing allocation is determined as the one where producer earnings minus costs are maximized.

To determine consumer surplus for a given set of prices, we proceed as follows. For each route and time slot, fix the prices of other routes and slots at the chosen levels. Consumer surplus on a route and slot is then equal to the total benefit for the actual travel minus the fares paid. This is illustrated for the case of one route and two time slots in Figure 2. Actual quantities of travel in the two time slots are denoted by q^{1*} and q^{2*}. Because they are gross substitutes (and obey the law of demand), an increase in the price on market 2 will decrease Q^2 but will also cause the demand curve for Q^1 to shift outward. To determine the "location" of the two demand

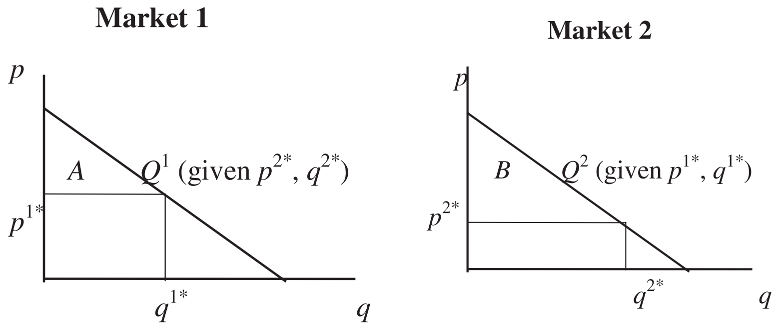

FIGURE 2

CONSUMER SURPLUSES IN TWO MARKETS

curves, we fix them at the location determined by the price (and quantity) actually chosen in the other market. In this example, total consumer surplus is equal to the area of triangle A plus that of triangle B. Producer surplus is equal to the fares charged minus the total costs.

4. EXPERIMENTAL DESIGN AND PROCEDURES

Our experiments study the behavior of subjects on the simple network presented in the previous section. It will be argued below that this network captures the most important characteristics of the Dutch railway system. Subjects are split in groups of four that remain constant throughout the experiment.[8] The experiments include multiple rounds, each with two parts. In part A of a round, the rights to schedule trains on various routes are allocated. In part B, operators decide what routes to schedule (an operator can only schedule on a route he/she has the rights to) and, in one treatment, what prices to charge passengers for the scheduled routes. The monetary unit used in the experiments is the experimental franc. The subjects were informed that these would be converted to Dutch guilders at a rate of 300 francs = 1 guilder. At the time when the experiments were run, 1 guilder = \$0.50. In each round, subjects were given a lump-sum payment of 3000 francs.

4.1. *Allocation of Rights.* There is no incumbent train operator in the experiments; all potential operators have equal access to rights to use the tracks. The allocation of rights is made by auctioning them in part A of each round. Two methods are used. In experiments with competition *on* the rails, each route/time-slot combination is a separate good to be obtained in the auction. Given the synergies in demand (actual travel depends on what happens in other route/time slots), it is important to use a combinatorial auction in which bidders can submit "all or nothing" bids on any feasible combination of routes. We use a multiround combinatorial auction in which bidders can submit bids on any combination of routes and time slots. The bidders can revise their bids when the auction is open.

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[8] At most four groups participated in any single session.

In addition, they can submit multiple bids in any single round of bidding. When the market closes, the auction uses a first-price rule for calculating market prices; that is, winning bidders pay the amounts of their bids.

In experiments with competition *for* the rails, subjects bid on monopoly rights for regions A and B and for the interregional route. They submit price bids for the trains they will schedule. Bids take the form of one peak and one off-peak price that apply to all routes. Bids are ordered by weighting the peak price by 1 and the off-peak price by 2 and summing. These weights reflect the relative magnitudes of baseline travel in the peak and off-peak time slots and the numbers of the two types of slots. The lowest bid for each region that results from this aggregation is the winning bid for those rights. In this case, we did not use a combinatorial auction. Given the fact that we only distinguished three regions and that subjects could submit simultaneous bids, we thought that combinatorial bidding would be an unnecessary complication.[9]

This specific allocation and pricing procedure was requested by the Ministry. This kind of "forced" choice is typical for the kind of wind-tunnel experiments we are undertaking. If we had been undertaking these experiments from a purely academic point of departure, we would have introduced fewer differences between the two procedures. Apart from the differences in the two mechanisms, we kept the auction rules as similar as possible. In both cases, a maximum of seven bids per round was allowed. In addition, a maximum of 10 bidding rounds was held. After round 3, no new bidding round was started if the previous standing bids were not improved. These rules were explained to all of the subjects.

4.2. *Route Scheduling and Pricing.* In competition *for* the rails, winning bidders are required to run trains on the routes and time slots in a minimum schedule. They may also run trains on routes and time slots that are not in the minimum schedule but must charge the peak and off-peak fares that they bid in the auction for all trains, whether in the minimum schedule or not. Because the particular minimum schedule imposed by the government might affect the outcome of the experiments, two alternative minimum route schedules are used as experimental treatments. In one treatment, the minimum schedule was relatively efficient (EF) and in the other it was relatively inefficient (IE).[10] The actual minimum schedules used are presented in Appendix A.2.

In part B of a round, operators have to determine schedules for running trains on the parts of the network for which they obtained the rights. A schedule consists of a decision whether or not to run a train for every allocated right in every time slot. Scheduling is done with the aid of a computer program that imposes the network feasibility (or train noncollision) constraints. For example, consider the case where in the bidding part of an experiment a subject obtained the rights for routes A_1A_2 and A_2A_3 in time slot t (note that these routes are always allocated to one subject in

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[9] In a pilot study where a combinatorial auction was used for this case, virtually no combinatorial bids were made.

[10] We did not provide a minimum schedule that is a proper subset of the most-efficient profitable schedule to be presented below. This way, we do not push the subjects towards efficiency. Moreover, both minimum schedules can be developed in a perfectly symmetric way (see Appendix A.2).

competition *for* the rails). In that case, the scheduling software would permit the subject to schedule local trains on routes A_1A_2 and A_2A_3, or an express train on route, A_1A_3, for time slot t. The software would not allow scheduling of A_1A_3 together with either A_1A_2 or A_2A_3.

In experiments with competition *for* the rails, operators must run trains on the routes in the minimum schedule but can add trains on other routes. In experiments with competition *on* the rails, operators are free to schedule or not schedule trains on any routes for which they obtained the rights. In addition, in the scheduling part of experiments with competition *on* the rails, operators need to choose peak and off-peak prices for those routes on which they schedule trains.

Operators schedule trains and (where applicable) set prices without knowing the decisions of other operators for other parts of the schedule. Once a schedule has been set, travel is simulated and this determines the earnings of the operators.

After scheduling and (where applicable) pricing is completed, operators are told their earnings. They are then allowed to make a new schedule for the same allocation of rights. This is used to determine the earnings again. For each allocation of rights, the scheduling is done twice in competition *on* the rails and six times in competition *for* the rails.[11] Then, a new round is started where part A is used to allocate rights and part B is again undertaken several times. The two-part rounds are run three times in every condition.

4.3. *Operator Earnings.* Operators make money by transporting (simulated) passengers. The amount they make depends on the number of travelers they transport on various routes and time slots, the prices they charge, and the costs of running a train. These costs have two elements. First, there are fixed costs of leasing trains. Once a train is leased, it can be used for different routes in different time slots, as long as this is physically possible in the way discussed above. Second, there are variable costs of running trains on routes. These variable costs are independent of the number of passengers transported (i.e., the marginal costs for an additional passenger are equal to zero). A subject's earnings are equal to her revenues (the summation of prices times numbers of travelers on various route and time slots) minus the fixed and variable costs.

4.4. *Subjects.* Subjects in the experiment represent the train operators. They are recruited from the undergraduate population of the University of Amsterdam. Subjects are first brought in for a 3-hour training session. In this session, they practice making schedules (including price schedules). These training sessions consist of three phases. The first two are only concerned with part B of the experiment. Subjects are paid a fixed fee of 60 guilders ($30) for participation in the training session. This fee is paid after the actual experimental session has taken place.

In *phase 1*, subjects are allocated the rights to use all routes and time slots. They are allowed to try all kinds of combinations of routes and prices to see what the effects are.

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[11] The difference in the number of scheduling rounds was at the explicit request of the Ministry. It reflects differences in the duration they would let the licenses be valid in the two mechanisms.

In *phase 2*, we preset the trains scheduled on several routes and time slots and let the subjects decide on the remaining ones. Before they make their schedules, we inform them of which routes and time slots they are not responsible for scheduling. Then they have to make a schedule of trains for their own routes and time slots knowing what trains have been scheduled on the other routes and time slots in the preset schedule. They do so for each of the preset schedules within 45 minutes. In this phase, subjects' earnings are recorded. These are not paid to the subjects but used to select subjects for participation in the experiment itself.

In *phase 3*, the subjects practice the auction mechanisms to be used in part A of the experiments. The subjects that make the most money in phase 2 are allowed to participate in the actual experiment. This procedure was explained to the subjects.[12]

4.5. *Network, Demand, and Cost Parameters.* We use five time slots; that is, $T=5$. As described above, we start with a baseline number of travelers when determining actual travel. This baseline number varies across routes but is the same in time slots $2,\dots,5$. Time slot 1 is the peak demand slot. In time slot 1, the baseline travel is twice the (common) level in the other slots.

The baseline travel quantities, V_{ij}^t, are equal for both track directions connecting any two stations; that is, $V_{ij}^t = V_{ji}^t$ for all t, for all i,j. Figure 3 shows the baseline travel quantities that we use in the experiments for time slots 2–5. For example, $V_{A_1A_2}^t = V_{A_2A_1}^t = 60$ for $t=2,\dots,5$. Baseline travel quantities for time slot 1 are twice the amounts in Figure 3.

Recall from our discussion of the structure of demand in Equation (1) that the term involving α gives time substitutability: there is less travel if the same route was traveled in an adjacent time slot. The term involving β gives station complementarity: There is more travel if there is a connecting train in the same direction in either the previous or the next period. We use the specific values $\alpha=0.2$ and $\beta=0.3$ in the experiments.

The specific values of the cost parameters used in the experiments are as follows. The fixed cost of leasing a train is set at $c^1=2000$ francs. The variable cost of running a train on any route is set at $c^2=300$ francs.

4.6. *The Benchmark Schedules for the Design Parameters.* Using the design parameters, we can use numerical methods to determine the benchmark schedules described in Section 3.2. These are the efficient schedule, the most-efficient profitable schedule, and the profit-maximizing schedule.

Because of the cost structure chosen, the efficient schedule involves prices equal to zero. The reason is that, given that a train has been scheduled on a particular route, the marginal cost of transporting an additional passenger is equal to 0. Thus, as long as these additional passengers generate a positive benefit from the ride, it is efficiency enhancing to have them on the train. This is accomplished by setting prices equal to 0. For the V_{ij}^t, c^1, c^2, α, and β parameter values of our experimental design,

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[12] About 75 percent of the participants in the training sessions participated in the experiment itself. The others were told at the start of the experiment that they could not participate, paid the fee for the training session, and sent off.

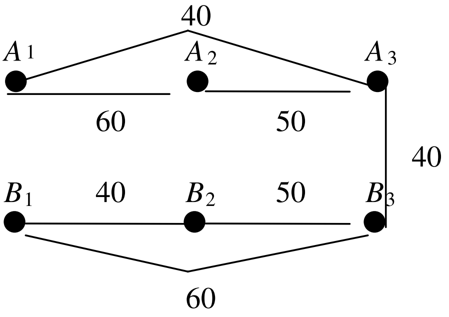


FIGURE 3

BASELINE TRAVEL QUANTITIES

maximization of consumer plus (negative) producer surplus subject to prices equal to zero gives the schedule portrayed in Figure 4. A short arrow denotes a local train running in the direction of the arrow. A long arrow denotes an express train. Thus, the period 1 efficient schedule has local trains running on the routes A_1A_2, A_3A_2, and A_3B_3 and express trains running on the routes B_1B_3 and B_3B_1. The efficient schedule uses five trains and has a number of interesting features. It does not favor either competition *on* or competition *for* the rails; in both treatments, this schedule can be reached. In one of the two regions, express trains are run in period 1; in the other region they are not. In periods 2 and 4, the local trains run in opposite directions than they do in periods 3 and 5. The total surplus for this schedule is 123,308.

The most-efficient profitable solution for the experimental design parameters is calculated with an optimization algorithm that maximizes the sum of consumer's and producer's surplus subject to the constraint that revenue is greater than or equal to cost. The resulting schedule of trains is the same as that for the efficient schedule but, of course, the prices and efficiency are different. To schedule these trains without making a loss, a (peak) price of 36.61 is charged in period 1 and an (off-peak) price of 0 is charged in periods 2–5. It is optimal to subsidize trains in off-peak periods with the profit obtained during the peak period. The consumer surplus gained in periods 2–5 by setting prices equal to zero is larger than the surplus lost by raising the price

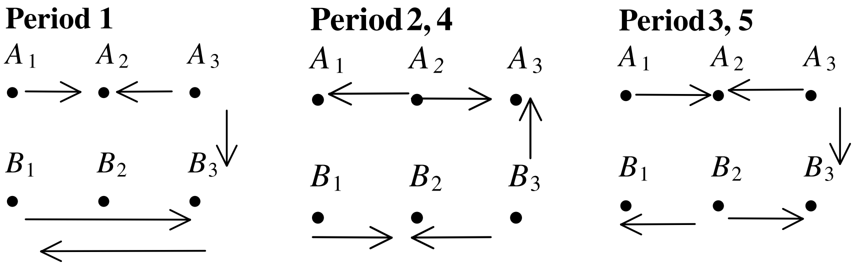


FIGURE 4

THE EFFICIENT SOLUTION AND THE MOST-EFFICIENT-PROFITABLE SOLUTION above the break-even point in period 1. The total surplus for the most-efficient profitable solution equals 102,164. This implies a welfare loss of 17.1 percent compared to the zero-price efficient allocation. Of course, this cost is unavoidable unless the government has some other way to compensate operators for their losses than having them charge passengers for their transportation. The two minimum schedules used in competition *for* the rails were derived from this schedule. They are presented in Appendix A.2. In both cases, three trains are used. In the relatively efficient (EF) schedule, there is an express train going back and forth on B_1B_3 and B_3B_1, a train connecting to this express train and going back and forth on A_3B_3 and B_3A_3, and a local train moving through region A (connecting to the train on A_3B_3 and B_3A_3, when it arrives at and leaves from A_3). In the relatively inefficient (IE) schedule, there is an express train going back and forth on A_1A_3 and A_3A_1, a train *not* connecting to this express train and going back and forth on A_3B_3 and B_3A_3, and a local train moving through region B (*not* connecting to the train on A_3B_3 and B_3A_3 when it arrives at and leaves from B_3).

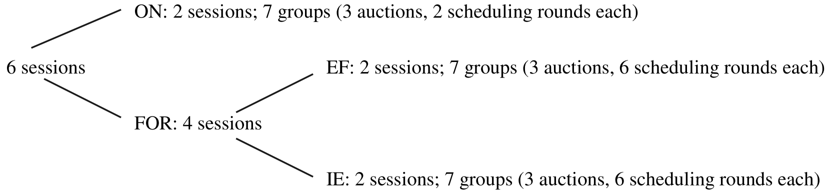
The third benchmark we will use is provided by the schedule and prices that would be set by a monopolist with the right to use the whole network without restrictions. A monopolist would again use the scheduling of trains given in Figure 4. She/he would charge profit-maximizing prices of 53 during the peak period and 24 during off-peak periods. This yields a consumer surplus of 33,908 and a producer surplus (profit) of 22,208, for a total surplus of 56,116. The efficiency loss compared to the most-efficient profitable schedule is 45 percent.

4.7. *Relating the Experimental Design to the Main Characteristics.* In Section 2, we listed the main characteristics of the Dutch railway network. Now we can compare these with the characteristics of the experimental railway network. First, the infrastructure is given for the subjects. Next, the setup treats each route/time slot as a marketable good and allows for complementarities and substitutabilities. In addition, the cost structure distinguishes fixed and variable costs and sets the marginal costs for an additional passenger equal to zero. Prices may be different in peak period 1 than in off-peak periods 2–5. The demand structure is known to operators and Equation (1) captures the elements of the demand structure described in Section 2.

4.8. *Summary of the Sessions.* Figure 5 summarizes the experimental treatments.

5. EXPERIMENTAL RESULTS

We compare the performance of competition *on* the rails with both the relatively efficient and relatively inefficient treatments of competition *for* the rails. Performance evaluations are based on several criteria: the lowest weighted price charged to passengers; the number of scheduled trains and the number of passenger trips; and the highest efficiency level as well as the distribution of realized surplus. Note that the price and the number of trains and passengers are directly related to the government goals described in Section 1: low fares and a dense schedule of trains.



ON = competition on the rails; FOR = competition for the rails; EF = relatively efficient minimum schedule; IE= relatively inefficient minimum schedule

FIGURE 5

SUMMARY OF THE SESSIONS

Efficiency and distribution are more general economic criteria, though they are related to the government's wish to raise revenue and reduce subsidies, of course. When discussing efficiency, we will sometimes be forced to compare the observed surplus to the zero-price benchmark. This is explained below. In most cases, the comparison will be to the most-efficient profitable allocation, however.

Recall that in competition *for* the rails the rights to schedule are auctioned three times. For each allocation, subjects provide six schedules. Thus, in total 18 schedules per group are produced in competition *for* the rails. In contrast, in competition *on* the rails, subjects provide only two schedules for each of the three times the rights are allocated. In total, we have six schedules per group in the treatment concerning competition *on* the rails. In the analysis, we sometimes refer to one schedule as one "year." Thus, we have observed 18 years in competition *for* the rails and 6 years in competition *on* the rails. This difference reflects the Ministry's plans with respect to the number of years for which licenses would be granted in the alternative privatization policies.

5.1. *Peak and Off-Peak Prices.* One item of central concern in choosing between privatization policies is the price of travel. Table 1 reports the prices observed in our experiments with competition *on* the rails (*ON*) and competition *for* the rails with the relatively efficient minimum schedule (FOR_{EF}) and the relatively inefficient minimum schedule (FOR_{IE}). The figures reported are quantity-weighted prices, averaged across groups and years. Competition *on* the rails produced higher prices for both peak and off-peak travel than did either treatment with competition *for* the rails. If we use average-weighted price per group as the unit of observation, there are significant differences between both *ON* and FOR_{IE} (Mann–Whitney: $m=7, n=7; p=0.00$) and *ON* and FOR_{EF} (Mann–Whitney: $m=7, n=7; p=0.00$).[13] Competition *for* the rails with the inefficient minimum schedule produced higher prices than it did with the efficient schedule, but the pricing difference between

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[13] All reported tests use averages per group as data-points. Unless indicated otherwise, the same results are obtained if attention is limited to the first 6 years in the for-the-rails experiments.

Table 1

WEIGHTED PRICES, AVERAGED ACROSS GROUPS AND YEARS

Treatment	Period 1 (peak)	Periods 2–5 (off-peak)	All Periods
ON	53.75	24.03	33.48
FOR_{EF}	20.59	12.72	15.02
FOR_{IE}	24.15	13.77	17.06

Note: prices are denoted in francs; weighted average price = $\sum_j P_j Q_j / \sum_i Q_i$.

FOR_{IE} and FOR_{EF} does not reach conventional significance levels.[14] Furthermore, the difference between FOR_{IE} and FOR_{EF} is much smaller than the pricing difference between either of them and the on-the-rails treatment.[15]

Table 1 reports prices that are averaged over both groups and years within treatments. In order to fully understand the price differences between treatments, it is necessary to separate these two types of averaging. Do average prices in the on-the-rails experiments start high but then decrease, so that the difference from the for-the-rails average prices disappears with subject experience, or are the price differences stable over time? Figure 6 presents graphs of the time series of average prices. We observe that the average price differences among treatments are stable over time.[16]

If we compare the average prices to the prices in our most-efficient profitable benchmark, we note that none of the observed prices are close to 36.61 in period 1 or 0 in periods 2–5. Note that it is not individually rational for operators to run trains and charge price 0, however. When comparing to the profit-maximizing prices (53 in period 1 and 24 in periods 2–5), it appears at first sight that the prices in *ON* are quite close. The average profit made from operating trains is 6452.52. This is far below the profit in the monopoly benchmark (22,208). Apparently, subjects are unable to (coordinate and) run the profit-maximizing schedule.

Subjects are able to make profits in the experiments. In FOR_{EF}, the average profit per schedule equals 7487.41 (here profits of all providers in all five periods are aggregated). In FOR_{IE} the average profit per schedule falls to 1827.41. In the on-the-rails experiments, average profits are equal to 6452.52.

5.2. *Train Service and Passenger Trips.* The frequency with which trains run on the network (the number of route/time slots scheduled) and the number of passengers transported are important considerations in choosing a privatization policy. Table 2 reports the average number of route/time slots in which trains were

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[14] The difference between FOR_{EF} and FOR_{IE} is significant if we only consider the first 6 years.

[15] It is a consequence of our wind-tunnel design that we are unable to establish whether the price differences between *ON* and *FOR* is completely due to the different auction designs or that the competition form itself has an effect. As suggested by a referee, this could be the topic of a whole new set of experiments.

[16] The fact that prices are almost constant within each round of 6 years in the for-the-rails experiments is to a large extent explained by the fact that subjects have to charge the same price for each year of a round. Nevertheless, small shifts in weighted-average price may result if the number of transported passengers change within a round.

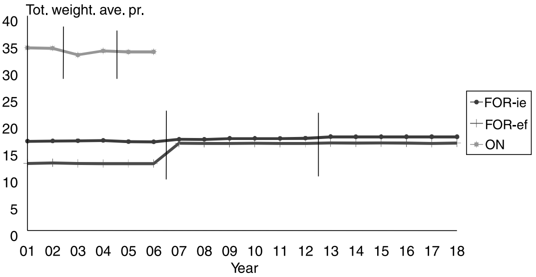

FIGURE 6

TIME SERIES OF TOTAL WEIGHTED-AVERAGE PRICES

TABLE 2

ACTUAL AVERAGE QUANTITIES AND ROUTES PER SCHEDULE

Treatment	No. of Route/Time Slots Scheduled	No. of Transported Passengers	Ave. No. of Passengers per Train
ON	27.07	1073.12	39.64
FOR$_{\mathrm{EF}}$	21.87	1518.55	69.44
FOR$_{\mathrm{IE}}$	27.57	1274.90	46.24

scheduled, and the average number of passengers that traveled on these trains, for each of the three treatments. Significantly more route/time slots were scheduled in both the on-the-rails experiments and the for-the-rails experiments with the inefficient minimum schedule than in the for-the-rails experiments with the efficient minimum schedule (Mann–Whitney *ON* versus *FOR*$_{\mathrm{EF}}$: $m=7, n=7; p=0.01$; Mann–Whitney *FOR*$_{\mathrm{EF}}$ versus *FOR*$_{\mathrm{IE}}$: $m=7, n=7; p=0.01$).[17] Nevertheless, despite the small number of routes scheduled in for-the-rails experiments with the efficient minimum schedule, the total number of transported passengers per schedule is higher than in both the on-the-rails experiments and the for-the-rails experiments with the inefficient minimum schedule. In the for-the-rails experiments with the efficient minimum schedule, there is a higher number of transported passengers per train ride than in the for-the-rails experiments with the inefficient minimum schedule. In the on-the-rails experiments, trains are relatively most empty.

5.3. *Allocative Efficiencies.* Economic efficiency is an important criterion for choosing between privatization policies. Table 3 reports allocative efficiency measures for our experiments. The second column reports that the total realized surplus was largest in the for-the-rails experiments with the efficient minimum schedule and that there was little difference between the surpluses realized in the other two treatments. Columns 3–5 in Table 3 report the decomposition of the realized surpluses into those

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[17] The difference between *FOR*$_{\mathrm{EF}}$ and *FOR*$_{\mathrm{IE}}$ is significant at the 10 percent level if only the first 6 years are considered.

TABLE 3

OBSERVED SURPLUSES

Treatment	Surplus	Consumer Surplus	Producer Surplus	Government Income	Actual/Maximum	
					MEP	Zero-Price
ON	37,333	21,976 (59%)	6453 (17%)	8904 (24%)	36.5%	30.3%
FOR_{EF}	62,458	54,971 (88%)	7487 (12%)	0 (0%)	61.1%	50.7%
FOR_{IE}	34,818	32,991 (95%)	1827 (5%)	0 (0%)	34.1%	28.2%

accruing to consumers, producers, and the government. Experiments with competition *on* the rails generated surplus for the government from the revenue collected from auctioning the rights to use the rails. The two for-the-rails treatments do not generate surplus for the government because bidding in those experiments is in terms of prices to be charged to passengers. Note that consumers obtained by far the highest percentage of the surplus in both of the for-the-rails treatments. In the on-the-rails treatment, the government captured more of the surplus than the producers but the highest share was still obtained by consumers.

The last two columns report the ratio of the realized total (consumer plus producer) surplus to the surplus implied by the most-efficient profitable (MEP) allocation (times 100) and the ratio of realized surplus to the efficient, zero-price surplus (times 100). Note that the most efficient treatment (FOR_{EF}) obtained 61.1 percent of the MEP surplus. The other two treatments obtained 34.1 and 36.5 percent of the MEP surplus. The surplus in FOR_{EF} is significantly higher than in both FOR_{IE} (Mann–Whitney: $m=7$, $n=7$; $p=0.00$) and *ON*(Mann–Whitney: $m=7$, $n=7$; $p=0.00$). The difference in surplus between FOR_{IE} and *ON* is not significant.

The surplus measures reported in Table 3 are averaged across groups and over time. As with price measures, one needs to separate these two types of averaging in order to fully evaluate the results. Figure 7 reports the time series of total realized surplus in the three types of experiments. Observe that the allocative efficiency differences among the three treatments were relatively stable over time. Only the surplus realized in *ON* shows a slightly increasing trend.

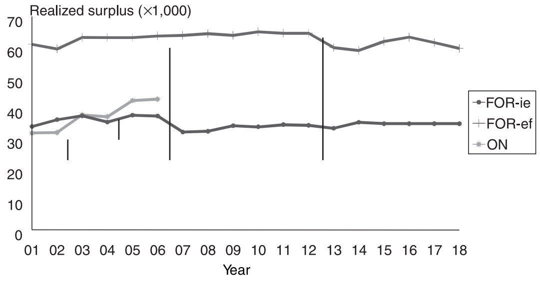

FIGURE 7

TIME SERIES OF SURPLUS

5.4. *Sources of Inefficiencies.* Less than optimal efficiency can be caused by both nonoptimal routing of trains and nonoptimal pricing of the transportation services of the trains. Table 4 reports the total efficiency losses for the three treatments and their decomposition into the losses attributable to nonoptimal routing and pricing. The second column reports the total efficiency losses for the three treatments; these numbers are equal to 1 minus the numbers in the third column of Table 3. The third and fourth columns show the decomposition. The decomposition is obtained as follows. For each schedule, we compute what the realized surplus would have been if providers would have charged a price of 0 francs to consumers for the routes that they actually scheduled. The difference between the maximum possible surplus and this hypothetical surplus is the efficiency loss due to routing. The difference between this hypothetical surplus and the actual surplus is the efficiency loss due to pricing. Note that in this case, we are forced to make a comparison with the zero price benchmark. When we observe a routing for a given subject, we cannot simply compare the surplus for her/his prices to that for the prices in the most-efficient profitable allocation because these prices will generally not be the most-efficient profitable ones for her/his routing. They might even make her/him incur a loss. The break-even prices will vary across subject, making this a useless benchmark for the analysis undertaken in this section. Therefore, we derive the results here using the zero-price benchmark.

Competition *on* the rails (*ON*) produced much larger losses from both nonoptimal routing and pricing than did competition *for* the rails with the efficient minimum schedule (FOR_{EF}). In fact, the surplus lost in *ON* due to routing alone is almost as large as the total loss in FOR_{EF}. Apparently, subjects have a hard time in coordinating their trains towards an efficient schedule in *ON*. In contrast, *ON* produced smaller losses from nonoptimal routing, and larger losses from nonoptimal pricing, than did competition *for* the rails with the inefficient minimum schedule (FOR_{IE}). Also note that about 59 percent (21.2/36.0) of the efficiency loss in FOR_{EF} is attributable to nonoptimal routing. This is close to the 56 percent (34.6/61.8) figure for *ON* but very different from the 86 percent (55.0/64.3) attribution to nonoptimal routing for FOR_{IE}.

5.5. *Bidding Behavior.* Experiments with competition *for* and *on* the rails used similar but not identical auctions to allocate the track property rights. Both used iterative sealed bid auctions. But in *ON* experimental sessions, bidders were allowed to bid on individual station and time slot routes, and the highest combination of bids won, whereas in *FOR* experimental sessions, bidders were restricted to bid on

TABLE 4

SOURCES OF EFFICIENCY LOSSES

Treatment	Efficiency Loss (%)	Due to Routing (%)	Due to Pricing (%)
ON	61.8	34.6	27.2
FOR_{EF}	36.0	21.2	14.8
FOR_{IE}	64.3	55.0	9.3

regions, and the lowest combination of bids (or fare structure) won. Even with these distinctions, there is little to distinguish bidding behavior in the two auctions. Bidders generally used the maximum number of iterations to complete each auction and the median number of iterations per period was 10 in both *FOR* and *ON* sessions. The median number of winning bidders was the same in both *FOR* sessions, in both cases 2. For the *ON* sessions, the winning number of bidders was 2 in periods 1 and 3, and 3 in period 2. The number of accepted bids was 3 in all of the *FOR* sessions (by design), and in all cases all three regions were allocated. In the *ON* sessions, the median number of accepted bids was 4 in round 1, 3 in round 2, and 2 in round 3; and the median number of accepted slots was 29 in round 1, 42 in round 2, and 50 in round 3. Thus, with practice, subjects were able to allocate more slots to fewer bidders in the *ON* sessions. In the *FOR* sessions, behavior did not change much between rounds except for the changes in price bids. This might indicate that the *ON* sessions were more difficult for the subjects than the *FOR* sessions.

5.6. *Implications of Network Monopoly.* As previously noted, in implementing the next stage in privatizing its passenger rail service, the Netherlands will be replacing a private unregulated monopolist. Of course, monopoly can result from any of the policy alternatives considered in our experiments, but the implications of monopoly can be very different in competition *for* the rails than in competition *on* the rails. Table 5 presents a decomposition of price and efficiency loss data according to whether or not the bidding stage of an experiment assigned the rights to the interregional route and both regions all to the same bidder. First compare the (weighted) prices observed to those in the monopoly benchmark (33.33). As noted above, prices in *ON* are quite close to this, but there does not appear to be a difference between cases where there was actually a monopoly and cases where there was not. Moreover, weighted prices were (on average) lower in monopoly than when there was more than one operator. This holds in all treatments. Apparently, monopoly pricing is not very prominent.

Next, compare the efficiency losses. In the case of *ON*, the greater inefficiency due to nonoptimal pricing with monopoly (32.7 vs. 25.0 percent) was more than offset by lower inefficiency due to routing (24.4 vs. 38.6 percent), with the result that total efficiency loss was lower with monopoly allocation of the rights. The *ON* treatment's lower efficiency loss from nonoptimal routing with monopoly assignment of rights

TABLE 5

EFFECTS OF MONOPOLY IN THE NETWORK

Treatment	Monopoly	Wt. Ave. Price	Efficiency Loss (%)	Due to Routing (%)	Due to Pricing (%)
ON	No	33.64	63.6	38.6	25.0
ON	Yes	33.07	57.1	24.4	32.7
FOR_{EF}	No	16.45	35.1	18.5	16.6
FOR_{EF}	Yes	11.44	38.3	27.8	10.5
FOR_{IE}	No	17.26	63.4	54.2	9.2
FOR_{IE}	Yes	15.86	70.2	59.9	10.3

can be explained by the monopolist's greater success in dealing with route/time slot complementarities and substitutabilities in demand.

In contrast, total efficiency losses were larger with monopoly for both FOR_{EF} and FOR_{IE}, and this resulted from the larger inefficiencies from nonoptimal routing that occurred with monopoly. This may seem puzzling, but can be better understood by keeping in mind that in the for-the-rails treatments without network monopoly, there were, by design, regional monopolies. It appears that subjects were better able to handle demand complementarities and substitutabilities when routing trains through one region than when attempting to deal with the complexities of the whole network.

6. SUMMARY AND CONCLUSIONS

This article reports a case study in the use of experimental economics in the formulation of public policy. The reported research illustrates both the advantages and disadvantages of this use of experimental methods. The principal advantages are the focus on important practical policy questions and the possibility of influencing subsequent policy recommendations. The most important disadvantage comes from the time and budget constraints that can be imposed when funding for the research is provided by an organization whose objectives are practical and political, not scientific. Thus, we report experiments on the two alternative policies being considered by the Ministry for privatizing passenger rail service in the Netherlands. And the Ministry based its subsequent policy recommendations partly on the results of the experiments. The disadvantage of the wind-tunnel design used here is that it made it infeasible to implement the type of crossed experimental design that would have revealed the separate effects of component parts of the two policies.

The two alternative approaches to privatization that were studied in our experiments were "competition *on* the rails" and "competition *for* the rails." Our implementation of competition *on* the rails consisted of experiments in which subjects first bid in a combinatorial auction for rights to schedule trains on the network and then scheduled trains and priced transportation services for the route and time slot rights obtained in the auction. Experiments with competition *for* the rails also consisted of two parts. In the first part, subjects bid for monopoly rights in two regions and one interregional route. Bids took the form of prices for supplying a prespecified minimum schedule; they included a peak-demand price and an off-peak price. Weighted averages of the two prices were constructed and the lowest such average-price bid was the winning bid. Two alternative minimum schedules were included as experimental treatments, a relatively efficient one and a relatively inefficient one. Providers were required to use the prices they bid in the auction not only to run the minimum schedule but also to run other routes. In the second part of a competition *for* the rails experiment, subjects scheduled trains on the network. They were required to schedule trains on route-and-time slots in the relevant minimum schedule and could schedule additional trains in the region(s) for which they won the monopoly rights in the bidding part of the experiment.

Subjects were paid salient monetary rewards that equaled the difference between revenue from simulated passenger demand and their costs. Revenue was equal to prices times quantities determined by the demand relations reported in Equation (1) and explained more fully in Appendix A.1. In a competition *for* the rails experiment, a subject's costs included fixed and variable costs of scheduled trains. In a competition *on* the rails experiment, a subject's costs included accepted bids for route-and-time slot rights in addition to the fixed and variable costs of scheduling trains.

Our experiments would have produced a more complete understanding of the alternative policies if we had been able to implement a crossed design consisting of the experimental treatments we did run plus treatments in which regional monopolies were allocated by a revenue-generating, high-bid auction and route/time-slot rights were allocated by a low-bid, passenger-fare auction with a minimum schedule imposed on the network. But the treatments we did run allow comparison of the policy alternatives specified by the Ministry, on-the-rails/high-bid and for-the-rails/low-fare-bid, if not a full understanding of why the alternatives have these properties.

Here, we compare results from the two experimental treatments that correspond to the policy alternatives considered by the Ministry. Which of the two privatization plans proposed is better depends upon the assumed objectives of the policy and their relative importance. It also can depend on whether or not one assumes that the government or its delegate could implement a relatively efficient rather than a relatively inefficient minimum schedule in the competition-for-the-rails/low-fare-bid plan. As a first step in choosing between these two privatization plans, it can be informative to rank the plans sequentially in terms of single assumed objectives, as follows. If collecting government revenue were the objective, then the preferred plan would (rather obviously) be the competition-on-the-rails/high-bid plan because the alternative does not yield any revenue. This, of course, was obvious from the two options that the Ministry had in mind from the beginning. If revenue is an important government objective, however, the government might be wise to have an alternative tested where for-the-rails competition is combined with an auction that allocates rights to the highest bidder. If minimizing rail transportation prices were the objective, then the preferred of the two plans would be the competition-for-the-rails/low-fare-bid plan. If providing many train departures were the objective, then the preferred plan would be competition-on-the rails/high-bid, unless one assumes that a relatively inefficient minimum schedule would be implemented in competition-for-the-rails/low-fare-bid. If either economic efficiency or simply transportation of a large number of passengers were the objective, then the preferred plan would be competition-for-the-rails/low-fare-bid, unless one assumes that the minimum schedule would be relatively inefficient, in which case there is not much difference between the plans.

The value of experiments like ours, with simple stylized scale models of complex environments, can be explained by analogy with the role of wind-tunnel experiments in development of new airplane designs. Ultimately, it is necessary to try full-scale implementation of a prototype new transportation policy, just as it is ultimately necessary to fly full-scale prototype airplanes with a new design. But problems *first* encountered when testing a full-scale prototype design are often very costly. Therefore, scale-model airplanes are first tested extensively in wind-tunnel experiments before any full-scale models are built. These wind-tunnel tests often yield results that lead to modifications in aircraft design, or choice of one design over alternatives. They often bring to light questions, and highlight design-objective tradeoffs, which were not previously fully understood. These are the types of benefits that can be obtained from laboratory experiments like ours.

Our economics ‘‘wind-tunnel’’ experiments make clear the importance of the following considerations in choosing between these two alternative privatization plans.

The minimum schedule: The experiments demonstrate the critical importance of wisely choosing the minimum schedule in a competition *for* the rails policy, if it is to be a better policy than competition *on* the rails, if it were to be implemented as a full-scale policy. Note, however, that it is unknown whether the government would choose a relatively efficient or a relatively inefficient minimum schedule. Of course, if one thought that the government was capable of choosing a *fully* efficient schedule then there would be doubt about a primary reason for privatization. Such observations go beyond the scope of this article, however.

The coordination problem: The experiments demonstrate the central problem of coordination that would be encountered in full-scale competition *on* the rails. This is coordination needed to optimize benefits to passengers across route and time slots served by different companies competing *on* the rails. Individual competing firms would have to find some procedure for addressing this problem. Furthermore, if such companies set up a coordination board to address the problem, this could lead to collusion in restraint of trade and produce monopoly pricing.

The objectives of public policy: The experiments demonstrate that which policy is preferred depends on the relative importance that is assigned to several possibly conflicting objectives of public policy for passenger rail transportation. A more subtle insight provided by our experiments is the demonstration that the relative importance assigned to policy objectives would interact with the type of minimum schedule implemented in a competition *for* the rails policy to determine whether it serves the public better or worse than a competition *on* the rails policy in a full-scale rail network.

The experiments helped the Ministry to formulate the policy document, ‘‘de derde eeuw spoor’’ (the third century of the railways). This discusses market institutions that might be used in the next few years. Both the research described in our article and empirical research on experience with competition regimes outside the Netherlands led to a recommendation to introduce competition in a ‘‘*for* the rails’’ design instead of an ‘‘*on* the rails’’ design. This line of policy is described in a bill, ‘‘Concessiewet personenvervoer per spoor’’ (law for a concession for passenger transport via railways) that is currently under consideration by Parliament. The Ministry has chosen to introduce competition in stages. First, unprofitable lines are contracted out. Next, a new high-velocity line will be contracted out in a competition *for* the rails regime. The main part of the network is tendered to the incumbent firm, NS, until 2010. For the period after 2010 all options are still open.

APPENDIX

A.1. *Calculation of Efficiencies in the Experiments.* The efficiency numbers that we report are: $z^k = (E^k/E^o) \times 100$, where E^k is the realized sum of consumer and producer surpluses in all periods of experiment k and E^o is the surplus from optimal pricing and allocation of trains in all time periods.

Producer surplus in a period of experiment k is simply the sum of all sellers' revenues minus the sum of all sellers' costs in that period.

Consumer surplus in a period of experiment k is calculated as follows. First recall the "actual travel equations" that appear as Equation (1). There are 70 of these equations, one for each route and time slot. Consumer surplus for a period in an experiment is calculated using the observed quantities (Q_{ij}^t), the observed prices (p_{ij}^t), the experimental parameters (V_{ij}^t, α, β), and these 70 equations.

For present purposes, it will help to rewrite Equation (1) as follows

$$Q_{12}^t = V_{12}^t - p_{12}^t - \alpha(Q_{12}^{t-1} + Q_{12}^{t+1}) + \beta Q_{23}^{t+1} \tag{A.1}$$

$$Q_{13}^t = V_{13}^t - p_{13}^t - \alpha(Q_{13}^{t-1} + Q_{13}^{t+1}) + \beta Q_{34}^{t+1} \tag{A.2}$$

$$Q_{23}^t = V_{23}^t - p_{23}^t - \alpha(Q_{23}^{t-1} + Q_{23}^{t+1}) + \beta(Q_{12}^{t-1} + Q_{34}^{t+1}) \tag{A.3}$$

$$Q_{34}^t = V_{34}^t - p_{34}^t - \alpha(Q_{34}^{t-1} + Q_{34}^{t+1}) + \beta(Q_{13}^{t-1} + Q_{23}^{t-1} + Q_{45}^{t+1} + Q_{46}^{t+1}) \tag{A.4}$$

$$Q_{45}^t = V_{45}^t - p_{45}^t - \alpha(Q_{45}^{t-1} + Q_{45}^{t+1}) + \beta(Q_{34}^{t-1} + Q_{56}^{t+1}) \tag{A.5}$$

$$Q_{46}^t = V_{46}^t - p_{46}^t - \alpha(Q_{46}^{t-1} + Q_{46}^{t+1}) + \beta Q_{34}^{t-1} \tag{A.6}$$

$$Q_{56}^t = V_{56}^t - p_{56}^t - \alpha(Q_{56}^{t-1} + Q_{56}^{t+1}) + \beta Q_{45}^{t-1} \tag{A.7}$$

$$Q_{65}^t = V_{65}^t - p_{65}^t - \alpha(Q_{65}^{t-1} + Q_{65}^{t+1}) + \beta Q_{54}^{t+1} \tag{A.8}$$

$$Q_{64}^t = V_{64}^t - p_{64}^t - \alpha(Q_{64}^{t-1} + Q_{64}^{t+1}) + \beta Q_{43}^{t+1} \tag{A.9}$$

$$Q_{54}^t = V_{54}^t - p_{54}^t - \alpha(Q_{54}^{t-1} + Q_{54}^{t+1}) + \beta(Q_{65}^{t-1} + Q_{43}^{t+1}) \tag{A.10}$$

$$Q_{43}^t = V_{43}^t - p_{43}^t - \alpha(Q_{43}^{t-1} + Q_{43}^{t+1}) + \beta(Q_{64}^{t-1} + Q_{54}^{t-1} + Q_{32}^{t+1} + Q_{31}^{t+1}) \tag{A.11}$$

$$Q_{32}^t = V_{32}^t - p_{32}^t - \alpha(Q_{32}^{t-1} + Q_{32}^{t+1}) + \beta(Q_{43}^{t-1} + Q_{21}^{t+1}) \tag{A.12}$$

$$Q_{31}^t = V_{31}^t - p_{31}^t - \alpha(Q_{31}^{t-1} + Q_{31}^{t+1}) + \beta Q_{43}^{t-1} \tag{A.13}$$

$$Q_{21}^t = V_{21}^t - p_{21}^t - \alpha(Q_{21}^{t-1} + Q_{21}^{t+1}) + \beta Q_{32}^{t-1} \tag{A.14}$$

The following steps calculate the consumer surplus in a period of an experiment.

Step 1: To solve the above system of equations, a slack variable, which is positive if and only if demand is positive, is added to each equation; the solution to the resulting set of equations Q_{ij}^t is found for a given set of prices.

Step 2: Consumer surplus in each market is $S_{ij}^t = (Q_{ij}^t)^2/2.0$. Total consumer surplus in this period of this experiment is $CS = \sum_{i,j,t} S_{ij}^t$

A.2. *Relatively Efficient and Inefficient Minimum Schedules.* Each of the minimum schedules can be scheduled with three trains. The difference in the relative degree of efficiency of the minimum schedules is caused by the fact that the relatively efficient minimum schedule yields some complementarities that are lacking for the relatively inefficient minimum schedule.

First recall the efficient schedule presented in Figure 4. The relatively efficient minimum schedule used for the sessions FOR_{EF} is given by the three trains described in Figure A.1. With these three trains (and prices equal to zero) an efficiency of 61.8 percent is obtained. Adding trains can yield substantial efficiency gains. Note that this minimum schedule can be realized even if the regions are allocated to three different operators.

The relatively inefficient minimum schedule used for the sessions FOR_{IE} is given by the three trains described in Figure A.2. With these three trains (and prices equal to zero), an efficiency of 15.2 percent is obtained. Adding trains can yield substantial efficiency gains. Note that this minimum schedule can be realized even if the regions are allocated to three different operators.

Comparing the EF and IE minimum schedules, note that they are mirror images in the sense that the trains in regions A and B are switched. The substantial effect this has on efficiency is partly due to the differences in the baseline demand in these regions. More important is that the node complementarities in stations A_3 and B_3 are realized in EF but not in IE.

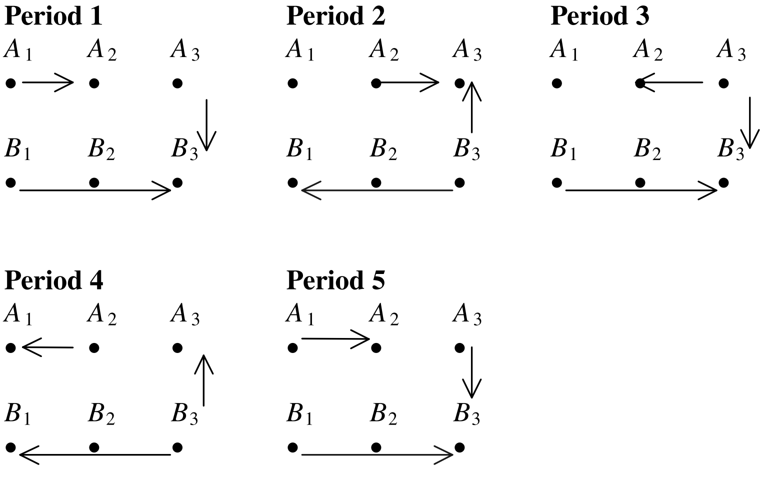

FIGURE A.1

THE RELATIVELY EFFICIENT MINIMUM SCHEDULE (EF)

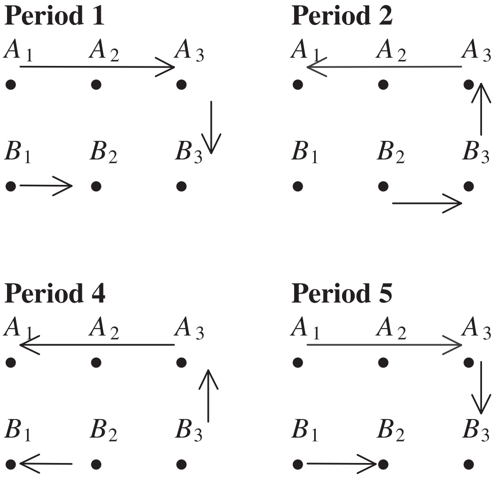

FIGURE A.2

THE RELATIVELY INEFFICIENT MINIMUM SCHEDULE (IE)

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