ALLOCATION OF TRACK CAPACITY
Experimental Evidence on the Use of Vickrey Auctioning in the Railway Industry

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Abstract: Allocation of track capacity features (a) multiple users with (b) demand indivisibilities that run trains over (c) an unresponsive supply of capacity, taken together implying (d) a technically complex optimisation problem. This paper suggests a Vickrey mechanism to handle incentive aspects of the allocation problem; the price for operating a train corresponds to the benefits foregone by others. The results of 16 experiments during which subjects have been bidding for routes over a railway network are reported. For 12 experiments solutions are in the range of 90-100% economically efficient. Experiment results are also used to provide an intuition for why railways while not other modes of transport are vertically integrated.

ALLOCATION OF TRACK CAPACITY: EXPERIMENTAL EVIDENCE ON THE USE OF VICKREY AUCTIONING IN THE RAILWAY INDUSTRY*

INTRODUCTION

1 Indivisibilities and uncertainty in demand, and a supply that is unresponsive to changes in demand creates allocation problems that are not readily amenable to standard methods for analysis. Examples of economic activities that have these features include airport scheduling (Rassenti et al 1982), NASA's planned earth orbiting Space Station (Banks et.al. 1989) and gas networks (McCabe et.al. 1989). The present paper suggests that allocation of railway track capacity is a problem of similar nature; track access provision means that trains are given right to use railway infrastructure according to a specified time table.

2 Railway infrastructure--tracks, signalling devices and possibly fixed installation for electricity supply--provide prerequisites for train movements. Once designed and built there are long time-lags to adjust capacity to changes in demand. Demand for track access is generated by the needs of passengers and freight customers to travel or dispatch freight loads between nodes in the network. Demand for single slots or routes is typically lumpy in time and geography. Going from Here to There at some time T is valuable if it is possible also to proceed to Elsewhere at an appropriate point of time. And while one departure time from Here typically has substitutes, the need to meet customer demand puts boundaries on flexibility. Customer needs also creates cyclical variations in demand with peak periods where available capacity is insufficient to meet demand and slack periods with under-utilised capacity.

3 Central to the track allocation problem is that if one train makes use of a certain section of track (a block) at one point of time, other vehicles can not use the same block at the same time. Since a block typically is much longer than the train, track allocation creates a problem that is different from the use of road infrastructure. And the combination of demand and supply indivisibilities creates a situation of immense combinatorial complexity when railway traffic is to be scheduled.

4 Analytically, the track allocation task includes two key features. First, conflicting demand for track access must be matched so as to maximise total value of a time-table. Secondly, incentives of participants in an allocation process to misrepresent preferences must be mastered. These are the optimisation and the incentive problems, respectively.

5 The generic way to time-table trains has been and still is to use administrative rules-of-thumb. By defining a pecking order over different classes of trains higher-ranked activities get priority over lower-ranked in conflict situations. In Europe, train scheduling is a several-months process to settle a time-table valid for one year at a time. The industry still has only very crude tools--at best, simple computer simulations to support intuition and ruler-and-pencil--to solve the problems at hand.

6 Economists are trained to expect inherent inefficiencies in centrally administered approaches to allocation. These arise from differential information, inappropriate incen-

tives and the existence of lobbying by what here is called priority groups. Given the traditional way to organise the railway industry as vertically integrated firms, these features have not until recently came to the surface. In contrast to (most) road, airport and harbour infrastructure, railway tracks are thus fully controlled by the operator using it. Moreover, at least in Europe, railways have been organised as nationalised monopolies.

7 The Swedish 1988 split of tracks and train operations into separate, still state-owned monopolies, pioneered a change of the traditional industry structure. Subsequently, similar reorganisations are underway in Germany and Great Britain. Sector reform also includes different ways to open up for competition on the tracks between firms operating on different market segments (passenger and freight and possibly sub-classes thereof) and even of oligopolistic competition on close-substitute niches of markets, as well as attempts to privatise all or parts of the industry. Furthermore, the EC has established its 'open tracks' policy, requiring member states (a) to (at least) separate operations and infrastructure in the books and (b) to give 'international groupings' of trains, including services of competitors, access to their infrastructure[i]. A further common feature of this declining industry - loosing business in particular to roads - is that change is politically ignited rather than driven by profit motives; massive public subsidies seems to be one explanation to that governments push for reform.

8 The purpose of this paper is to suggest a new way to handle the track allocation problem. While the method is feasible for application within a traditional, unified industry, the research has been ignited by the current push towards decentralisation and deregulation. A mechanism to handle the incentive problem that closely resembles the second-price auction suggested by Vickrey (1961) is therefore outlined in sections 2 and 3. Applying experimental techniques section 4 provides proof of principle that the mechanism for some simple applications is feasible and efficient, i.e. that it generates allocations that maximise social surplus. Section 5 elaborates on a simple vertical integration/separation framework to get closer to an intuition of why the railway industry up till now has been organised in the particular ways it has while section 6 concludes.

IDIOSYNCRASIES OF TRACK CAPACITY ALLOCATION AND A WAY TO SOLVE THE PROBLEM

9 Track capacity allocation includes the following features: (a) Railways often make up a network of lines between nodes. (b) The capacity of a line depends on if it is double- or single-tracked and the number of blocks of each line; a block is the shortest segment of a line that can hold one train at a time. Figure 1 gives an example of a single-track line with stations where trains can meet or overtake each other.

10 Different operators may run different classes of services, corresponding to different classes of trains in a unified industry, possibly running at different speeds. The pattern of demand can be wholly or partly overlapping in that operators may ask for routes over the network that are mutually exclusive; a route is a description of a train that leaves a station at a certain point of time, when it stops at consecutive stations and at what time it arrives at its destination. (d) Access to one specific section of the network is valuable

only if the same train also is allocated an adjacent block at the appropriate point of time. It is the full route rather than single blocks that has a value.

11 Routes may for two reasons have close substitutes. First, to take a (freight) train from departure to arrival station, different paths over a network may be used, possibly at different operating costs because of differences in route length etc. Secondly, the demand for one route may have time-substitutes since departures earlier or later in time than the 'ideal' may be acceptable. (f) The demand for a route of one operator may depend on whether another competing or co-operating firm is allocated a route 'close' to the first. One firms' value of a route may also depend on whether the same firm is allocated another complementary route. (g) Finally, in situations with excess demand for access to a block, supply can be increased only with a long time lag.

12 These features imply that the problem of finding a feasible and value-maximising allocation of track capacity can get immensely large and complex. It is, moreover, a technical problem in that it includes a binary restriction on the maximand; no more than one train at a time can occupy a block. This makes it impossible to apply traditional lagrangian techniques to identify marginality conditions in order to find an optimal solution.

13 In a separate project, a first attempt to apply Lagrange relaxation/dual optimisation, designed to handle this class of optimisation problems, has been studied (Fisher 1985 introduces the approach). The model has been tested on a 160 km single-track line in mid-Sweden. The line includes 17 stations/16 blocks. Running time for three classes of trains over these tracks has been coded. A situation with four firms (two passenger and two freight), running in total 18 (return) trains was assumed to be at hand. For each firm a profit function for getting track access is specified; the value to firm 1 to depart at 6.30 is, for instance, 625, tapering off to zero if the train has to leave before 6.15 or after 6.45.

14 For this problem configuration, close to 40 000 branches of a conflict tree were found to emerge; of these, only 225 had to be given a solution at the end of the exercise. This provides an intuition for the size of the problem. The model generates solutions 'close' to optimum within limited time, i.e. the technique seems to provide a feasible way to solve this class of problems; cf. further Brännlund et al (1993).

15 The present paper is, however, concerned with the incentive aspects of the optimisation problem; how make the different parties of the allocation process reveal their true value of track access, given the complexities enumerated above. To introduce the way that this is done, a string diagram is used. A string diagram depicts consecutive stations by horizontal lines while moves along lines represent time[ii]. A train-route is a string from one station to another; the speed is implicitly defined by the tilt of the string, i.e. the faster is the train, the steeper is the string. Strings crossing outside stations indicate prohibitive conflicts, i.e. that two trains travelling at these speeds in opposite direction collide or that a faster train catch up a slower. To the extent that operators ask for conflicting routes, these contests must be sorted out.

16 A simplified conflict is illustrated in Figure 2. In the same way as during experiments, multiplicity of blocks is abstracted from. Focus is on different classes of conflicts on a

single-track line between two stations. Route A and C are trains from station I to station II and route B in the other direction; routes B and C collide. The three routes are to be allocated between operators i-iii. Operator values of the routes are also specified.

17 One feature of the track allocation problem is that departures may have close substitutes in time. This is handled by assuming that each route has two alternatives departing k minutes before and after the preferred one. Alternatives are represented with a * before and after the string symbol; in the figure, only *B and B* are included. The three alternative versions of each route are assumed to be too close to allow any two of them to be operated simultaneously.

18 As it has been constructed, the B/C conflict can be solved either by forwarding departure B by k minutes to *B and let C operate in its preferred version or the other way round, i.e. B plus C*. To strike the balance between conflicting routes is a knapsack type of problem. In addition, the track allocation task includes also assignment problems, i.e. to decide which individual is to be given priority. To find the value-maximising balance, values of both preferred and secondary routes must be known. Here, secondary choices are assumed to be worth 2/3 of the basic value; the rationale for this assumption is given below.

19 The present set of experiments make use of a Vickrey (1961) type of auction. To illustrate how this works, assume that operators bid their values for the three routes. Operator (i) will then be allocated A, pays 1678--(ii):s bid--and makes a profit of (2319-1678=) 641. Furthermore, operator (iii) gets C and (ii) *B; the total value of this couple is (2220+2/3*1856=) 3457.

20 To trace the price that each has to pay, the benefits foregone by others has to be calculated. First, had it not been for (iii) bidding 2220 on C as assumed, (ii) would, *cet. par.*, have had B and (i) C*; the total value of that allocation is (1856+ 2/3*1112)=2597. This is the value of an allocation where the current winner of C is disregarded. Secondly, the value of the first-best allocation to others than (iii) is (2/3*1856)=1237. Third, the benefits foregone because of (iii) getting C is therefore (2597-1237=) 1360. This is the price that (iii) has to pay; her profit is 2220-1360=860. Along the same line of reasoning it can be shown that (ii) has to pay 1103 for *B making a profit of 134.

21 This simple example demonstrates the core features of the way that track capacity is allocated in this paper. Section 3 sets out the framework of a generic model of the track allocation problem.

DESIGNING A TRACK ALLOCATION MECHANISM

22 Think of a manager of infrastructure access (player 0), selling an intermediate good x (track access), used by i=1,...,I independent, downstream train operators. Railway operators in turn serve passengers and freight customers. Assume that agent i's utility of being allocated a unit of x depends on his own payment for the good p_i and type θ_i but not prices or types of others. Type is an external agent characteristic, here depicting profitability of operators and their single routes. Assuming also that i has von Neumann-

Morgenstern utility $u_i(x, p_i, \theta)$ with u_i decreasing in p_i, and with quasi-linear/risk neutral preferences we have [1]. If the principal furthermore is a benevolent maximiser of social surplus, and track infrastructure costs are not considered, we get [2].

23 $u_i(x,p_i,\theta_i) = V_i(x,\theta_i) - p_i \qquad i=1,,\ldots,I \qquad [1]$

24 $\underset{x}{\text{Max}}\ u_0(x,t,\theta) = \sum_{i=0}^{I} V_i(x,\theta) \qquad [2]$

25 This is a text-book example of an adverse selection problem where one party to a transaction knows things pertaining to the trade that are relevant but unknown to others. Using the mechanism design literature jargon, the mechanism that is to be defined specifies a message space M_i for each agent i, and a game form to announce messages. Because types are private information, the allocation of x can depend on θ only through the agent's messages. The task is to find a message rule such that individuals report their true type.

26 Think therefore of a planning process with the following key features. Operators register with the infrastructure manager the way in which they want to run each operation x^r, i.e. they specify the vector of departures (d) and arrivals (a) $\{t_1^d, t_2^a, t_2^d, \ldots, t_4^a\}$ of trains from/to stations. The route variable x^r is therefore short for a set of binary variables x_{st}^r with s=1,...,S for block and t=1,...,T a discrete measure of the time of the day (say minutes between 00.00 and 24.00); $x^r = \sum_s \sum_t x_{s,t}$. There are r=1,...,R routes and each firm may run one or more.

27 Also alternatives to the first-choice route are specified; rather than leaving station 1 at 7.00 it may be possible to depart 6.30 or 7.30 and still serve the market. In these specifications operators must make sure that it is technically feasible to run trains in the way requested. In other words, taking (a) physical limitations of rolling stock (acceleration capability, max speed etc.) and tracks (line-specific speed- and speed-/load restrictions) and (b) established safety restrictions into account, the schedule must be possible to operate, should no-one else ask for access; $x^r \in X$, X representing all technically feasible routes.

28 Except for the technical specification, a bid $b_i(x^r)$ is made for the route. This is a statement of willingness-to-pay for the preferred departure and of the reduced value if the route is forwarded or delayed in time. As illustrated by Figure 3, the value function may be fairly general.

29 Given this input, the infrastructure manager seeks to find the value-maximising solution to [3], the explicit version of [2]. The equation demonstrates the discrete nature of the constraint that generates a need to develop optimisation techniques other than those traditionally used; during experiments, soft-ware tailored to the respective conflicts has, however, been programmed.

$$\text{Max} \quad B = \sum_i \sum_r b_i(x^r)$$

30 $$\text{s.t.} \sum_r x_{st}^r \leq 1 \quad \forall s,t \qquad [3]$$

$$x^r \in X \quad \forall r$$

31 The optimisation generates a vector x^{*r}, $r=1,..,\rho,..R$, stating which routes to be operated by which operator, the total value of the allocation, B, and a price vector p^r to be paid by the operator being allocated route r. Current high bids, allocations and prices are revealed to everyone.

32 Because of the complexity of the track allocation problem, it was considered to be impossible to stick to a single bidding round. All different wishes taken together may generate solutions that are far from ideal departure/arrival patterns and a first allocation may generate insights about new approaches to operate services. Moreover, since there may be both positive and negative externalities in the network, operators may have an interest to co-ordinate services or to move away from competitors' routes. Operators were therefore allowed to change their bids. The bidding continues until no-one wants to make further changes.

33 The pricing rule is a version of the Vickrey (1961) second price principle; a firm allocated route x^ρ pays the benefits foregone by others because of this allocation. To be more specific, let $B^{-\rho} = \sum_{r=1}^{R} b(x^r) - b(x^\rho)$ be the value of an allocation without route ρ. $\hat{B}^{-\rho} = \max \sum_{r \neq \rho} b(x\ )$ is the optimal value of an allocation where route ρ is not operated. $\hat{B}^{-\rho} \geq B^{-\rho}$ since both expressions involves R-1 routes and since $\hat{B}^{-\rho}$ by definition is the optimum solution for that number of routes. The price of an allocated route, p^ρ, can now be defined in the following way[iii].

34 $$p^\rho = \hat{B}^{-\rho} - B^{-\rho} \qquad \rho = 1,\ldots,R \qquad [4]$$

35 This price is of a second-price nature in that the bid does not (directly) generate the price. If more than one operator bid for the same route, price equals the second highest bid. If the route is in conflict with other routes price is equal to benefits foregone when others are being pushed away from their first choice. The pricing principle differs from the Vickrey price in this latter complexity which emanates from the interdependencies of the track allocation problem. Another difference is that iterative rather than one shot bidding is allowed for. It resembles the Clarke-Groves tax in that for each route ρ with $p^\rho>0$, the route is pivotal, i.e. it has an effect on the total allocation outside itself; $p^\rho=0$ with only one bidder (cf. for instance the presentation of Clarke-Groves taxes in a mechanism design context in Fudenberg&Tirole 1991, ch. 6).

36 One original motive suggested by Vickrey for the second price principle was that each bidder can confine attention to appraising the value of an article in his own hands rather than deliberating over value or bidding strategy by others. As a consequence, more bid-

ders might be induced to participate in the process, resulting in a better allocation of resources and a higher selling price. There are another four motives here for choosing the Vickrey mechanism.

37 First, excellent research by others use the English auction (Brewer&Plott 1994). Secondly, under the Vickrey rules, bidding the true value is a dominant strategy, while under the English auction, a bid just above the second-highest bidders value is sufficient to get a route and will maximise the total value of the allocation. A Vickrey rule may therefore generate more accurate information about participants' willingness-to-pay; as will be further discussed in section 5, this may have a value of its own.

38 Significant parts of a railway network may be used by one or a few firms only. If this is so, Vickrey prices may generate lower prices than would an English auction. The third motive for the present mechanism is that a lower price delimits the uncertainty of possible entrants as well as incumbent operators. Rolling stock and other investment is expensive and can involve some sunk costs; if track access charges would be too large, and if it is difficult to tell at the investment date how large they actually would be this may be sufficient to make some firms abstain from entry. Fourth and finally, pricing track access can be conceived of as a congestion charge. A frequent argument in the indigenous debate is that it is not fair to price track congestion as long as corresponding charges are not levied in the road sector. To the extent that Vickrey prices generates lower charges than would emerge from a first-price auction, the importance of this alleged fairness issue is reduced[iv].

THE EXPERIMENTS

39 Auctioning of the right to operate routes according to Vickrey principles using an iterative bidding procedure is thus the candidate track capacity allocation mechanism. This section presents a series of experiments that have been conducted in order to assess incentive aspects of this process. Stylised sub-problems of the general allocation issue have been presented to students who in a laboratory setting bid for routes; the question is if realised allocations coincide with the optimal ones. Section 4.1 sets out the experiment testbed[v] and section 4.2 summarises results. The way that the experiments have been organised is presented in Appendix A and instructions in Appendix B.

The Testbed

40 Figures 4a and 4b introduce the <u>types of conflicts</u> that subjects have been confronted with during experiments; Figure 2 illustrates trade-offs between projects such as A/B of Figure 4a and D/E of 4b. Block interdependence, i.e. the need to co-ordinate allocation of one block (x_{st}) with (time- and location-) adjacent blocks, is ignored; $S \in \{1\}$. This is a trick to abstract from some complexity aspects of the problem and to focus on interdependencies within a block. While it is a restrictive limitation in that it dismiss one crucial dimension of the allocation problem, it may for two reasons be less disturbing. First, when the number of blocks increase, new ways to solve complex problems become available; this is so since siding trains at stations becomes one of the conflict resolution

tools. If it is possible to handle the single-block problem, and given that a functioning optimisation algorithm is available, it should also be possible to give the multi-block problem a solution. Secondly, when operators submit bids they are not aware of the detailed ways that conflicts are solved but merely know that trade-offs are made by change of departure time etc. The upshot is that what appears to be restrictive in reality may be just a way to concentrate on fundamentals.

41 Figure 4a has pairwise antagonism while Figure 4b depicts a situation with several strings/conflicts involved; either C or D/E and F can be operated. Each string is defined as having two alternatives, representing departures a few minutes before/after the ideal. Since a train typically has alternative departure times being equally or less valuable than the preferred route, and since even small time adjustments of a route may be sufficient to solve complex webs of conflicts, substitutability in the time dimension is an indispensable tool to handle conflicts of interest.

42 To model the situation of single operators, each route should therefore ideally have a number of more or less close substitutes. This however presents a problem to our student subjects; while the feature of routes having close substitutes and different values in the way modelled in Figure 3 above is obvious to any operator, it creates a difficult task to explain for persons unfamiliar with time-table scheduling problems. Brewer&Plott (1994) introduce time substitutability of routes by explicitly drawing alternative routes close to the preferred alternative. Here, each route has instead been defined to have substitutes. Each substitute is moreover defined to be valued at 2/3 of the basic option and a bid for a route is also a 2/3-bid for its substitutes.

43 Conflicts of Figures 4a and 4b can be unravelled in two different ways. The trade-off between routes A/B in Figure 4a and D/E of 4b can be solved by forwarding or delaying the departure of one or the other. While also projects--as the routes are called during experiments--G/H of 4a and A/B of 4b have close substitutes, the crash of interest is made so severe that it can not be resolved less than one of the two is deleted. The same goes for the Figure 4b choice between{D/E, F} and C.

44 For each auction, subjects **I**={1,2,...,6} are provided with a set of redemption values (V_i), one for each project k ($V_i(x^k)$); Table 1 gives an example. In accordance with the definition of alternative routes being worth 2/3 of the ideal, *A and A* is worth 327 to individual 1, 1437 to individual 3 etc.

45 Redemption values are randomly generated under two constraints. Assuming that participants bid the redemption value for each route - i.e. that $b_i(x^k)=V_i(x^k)\ \forall i,k$ (or $b_i=V_i$ for short) - each subject will, first, win at least one project per round; an exception is specified below. Secondly, if $b_i=V_i$ the profit over all 10 bidding rounds adds up to SEK450[vi] for each individual.

46 Experiments 10-12 are designed to handle the problems of Figure 4b. In some bidding rounds, the redemption values have been generated so that the value of C exceeds that of {D,E,F}. If $b_i=V_i$ there are five projects to be allocated between six individuals, i.e. some subject wins nothing. Most markets however have the combined value of {D,E,F} to exceed that of C. For these cases, redemption values have been generated with the

additional restriction that different individuals have the high redemption value for each route. As a result, these experiments test if subjects realise the need for (implicit) collusion; each has to bid (close to) redemption value in order to make the coalition {D,E,F} beat C.

47 Moreover, Experiments 13-15, while based on conflicts of Figure 4a, introduce a simple type of complementarity in redemption values between projects. The value of (say) A to individual i is 300 higher if he/she is also allocated (say) F. The individual may therefore bid up to 299 more than the redemption value of F in order to get the bonus. The economic intuition is that some routes/trains may earn different profits if they can be co-ordinated with others[vii].

48 The bidding rules of the experiments allow subjects to bid on any number of projects and to abstain from bidding. Ascending price adjustment and tatonnement-type bidding (bids can be both raised and reduced) has been tested. A bid for a route replaces the current high bid when it is strictly higher. Prices are determined using the principles of eq. [4]. Experiment subjects earn the difference between price established during the auction and their redemption value.

Results

49 Results will be reviewed under the following headings; efficiency of realised allocations (4.2.1); bench marking of results (4.2.2); analysis of final bids (4.2.3).

Efficiency

50 To explain the efficiency properties of the mechanism, consider Table 2a and 2b that summarises the results of experiment 6, auction 6 with redemption values provided in Table 1 and with the conflict configuration of Figure 4a. Table 2a details the allocation and profit, all participants bidding their redemption value for all projects (the value maximising solution), while Table 2b summarises the actual auction result. Individual no. 3 should be allocated project A and no. 6 project B*. This allocation is also the result of the auction. Since no. 6 has placed a bid for B that exceeds his/her redemption value for that project, the price to individual 3 is higher, and the profit lower than if everyone bid redemption values.

51 For project C, individual 4 is the high bidder with 1210 while no. 2 bids 1206, resulting in that 4 gets the project paying 1206. This is also the allocation if everyone bid their redemption value. Conflict E/F is not given the value maximising solution. First, subject no. 6 is the high bidder for project F, not no. 2. Secondly, E is implemented in its 'basic' version while F is adjusted to F*; the value maximising solution is the opposite. What has happened is that no. 2 has not realised the possibility to raise his/her initial bid of 500 for F. Most probably, the reason is that the subject did not understand that it is possible to raise the bid for a project when it (temporarily) is in its adjusted version (F*).

52 Table 2a includes the redemption values of the value maximising allocation; notice how the highest bidders (no. 6) redemption value of B is reduced from 1987 (cf. Table 1) to 1325 since B* is the optimal (and realised) allocation. Table 2b has corresponding val-

ues for the resulting allocation. The quotient between the sum of redemption values of realised and value maximising allocations is used as a measure of auction efficiency; to the extent that the two don't coincide, less than all benefits are realised. In this example the value is [(15216/15657)*100=] 97.2. Table 3 summarises this efficiency measure for all experiments.

53 Result 1a: 12 experiments out of 16 generates allocations that on average capture between 94 and 100% of potential benefits. For three single markets out of in total 101 less than 91% of potential benefits have been captured.

54 Result 1b: Four experiments out of 16 fail to generate results and are terminated with no or few observations.

55 Result 1b will be discussed in subsection 4.2.3. Result 1a is derived from Table 3; the basic message is that, in all cases where an experiment has been successfully brought to its end, the process generates allocations that on average capture most of the potential benefits that there are.

56 It is a priori reason to believe that more complex problems will be more difficult to give efficient solutions. Of the 12 successful experiments, five address conflicts more complex than the other 7 (for detail, cf. Appendix A). Experiments 10-12 include projects of type {D/E,F} vs. C where subjects have to 'co-operate' in order to capture all benefits; from Table 3, it can be seen that efficiency in these is only slightly below other results; of the 28 markets completed during experiments 10-12, only four have failed to sort out the complex conflict.

57 Experiment 7 has a tatonnement-type price adjustment rule; efficiency is close to 100%, but only 7 markets are completed. The reason is that each market takes a larger number of bidding rounds to clear the market, i.e. the experiment takes more time. Experiment 16 is the most complex of all in that it allows for both tatonnement-type bidding and in that there is value complementarity between some projects in the same way as under (the failed) experiments 13-15. Observed efficiency was high; handnotes from the lost result markets verifies that this was so throughout experiment 16. It should be noted that experienced subjects were used. We therefore state the following result.

58 Result 1c: There are no indications of that efficiency is severely affected by increasing the degree of complexity of conflicts and bidding rules.

59 Corollary: Tatonnement-like price adjustment can generate efficient allocations.

A Benchmark

60 A possible benchmark for comparison with observed results would be to solve conflicts randomly, i.e. to assign each route randomly between subjects, to sort out conflicts between routes randomly, and to calculate an efficiency statistic in the same way as above. Since 6 subjects have interest in each route and since route conflicts may be complex, randomly generated solutions would yield low efficiency ratings. A method to add substance to full randomisation is to combine it with some mechanistic rule of thumb and

see what additional discipline this adds on the allocation. Gode& Sunder (1993) discuss that approach for a double auction type of problem.

61 A different way to combine randomisation with complementary mechanistic allocation rules has been used here. Subjects' redemption values ranging from 1 to D are separated into m priority classes; class 1 includes individuals with redemption values between D and D(m-1)/m, group 2 values between D(m-1)/m and D(m-2)/m etc. For D=3000 and m=2, subjects with values between 3000 and 1500 belong to group 1 while group 2 have values between 1500 and 0.

62 Given the m classes, solve first the assignment problems. A route is allocated to the individual that belongs to the highest priority group; if more than one subject belong to that group the solution is randomised. Thereafter, resolve conflicts between routes using the same principle, i.e. resorting to randomisation only if conflicting routes have high-priority subjects that belong to the same group. Calculate the efficiency statistic for the resulting solution.

63 Excluding 'failed' experiments and assuming m=2, 4 and 6, conflict solutions have been generated and the efficiency number calculated. For each m, 100 solutions have been created in order to average out the impact of randomness. Table 4 gives the average efficiency for each experiment.

64 Experiments 1-7 and 9 have a common type of conflict situation; consequently, benchmark efficiencies are in the same range. The benchmark values are, moreover, surprisingly high. The reason is probably that redemption values have been rigged in a certain way; in order to make the expected gain of individuals equal to SKr 450, the high redemption value has now and again been adjusted upwards. As a result, randomisation is used only for a few cases when the benchmark solution is calculated. Except for experiments 2 and 3, observed average efficiency never the less exceeds the benchmark for all m.

65 Experiments 10-12 handle more complex trade-offs; benchmark efficiencies are therefore lower than for the first 8 cases. Again, observed average efficiency outperform the benchmark.

66 Result 2: Observed average efficiency is higher than benchmark efficiency with 6 priority groups in 9 cases out of 11.

67 The choice of m to generate a benchmark has no significance *per se*; indeed, as m grows, benchmark efficiencies will close in on 100%. What the benchmark can do, however, is to provide a hunch of whether observed results are the natural outcome of any approach to handle the allocation problem, or if it is the method under testing that has appealing qualities.

68 As it happens, this benchmark system has some properties in common with the way that trains are scheduled today. The present allocation system is thus one of conservatism, skilled personnel, priority classes and committees. A new time-table is, first, based on the existing one. Secondly, the personnel has extensive experience in trying to sort out

conflicts by rearranging departures. Third, remaining conflicts are handled by giving each train-class a priority[viii]; in conflicts of interest, high ranked trains get priority. Fourth, a committee with representatives of operating divisions discuss schedule proposals and make final adjustments.

69 There is no apparent way to model this process to provide a full-fledged comparison of experimental results to a probable 'real' outcome. The benchmark is, moreover, only an imperfect representation of present techniques. One reason is that it presumes the priority group concept to fully mirror the value of a train. In reality, a priority group can include trains with both higher and lower profits than implied by group ranking. Another reason is that it is difficult to model the *fingerspitz gefühl* of the personnel; often, this may generate much better results than implied by a randomisation procedure while at other instances - where the *gefühl* merely is prejudice - it overstates abilities.

Analysis of Individual Equilibria[ix]

70 To provide an intuition of the bidding strategies available to different individuals, consider the following taxonomy. A bid $b_i(x^k)$, x^k={*A,A,A*,*B...,H*}--henceforth b_i--is assorted according to its effect on the individuals potential profit, that is the profit an agent would make if the auction ends after this bid. A bid that increases agent i's potential profit is referred to as *pivotal*; this is a bid such that $b_i \leq V_i$ and $b_i > b_h$, b_h being the current high bid. A bid $b_i > V_i$ and $b_i > b_h$ is a *dominated* bid. Unless the dominated bidder has the highest redemption value and none else bid above his/her value, this reduces the potential profit of the bidder. A bid is said to be *dominated neutral* if $b_i > V_i$ but $b_i < b_h$. Under the Vickrey institution, dominated neutral bids will raise the price to the current high bidder. Any bid below the current second-highest bid for the route has no effect on either potential allocation or the price to be paid and is a *null bid*.

71 What may then an individually rational strategy look like? Just as under the 'clean' Vickrey auction, bidding redemption value is a strong candidate. This makes sure that the person never loose a project that he/she 'should' have had, and the other way round. In the present version of the mechanism, a bid for a project also represents bids for its alternative versions and the outcome may be that the bidder is allocated a second-hand choice. The principles guiding the allocation of routes make certain that this does not affect the principles of an optimal strategy; bidding redemption value for the 'premium' route could never be negative even if a 'secondary' route is being allocated.

72 Bidding dominated neutral bids that raise the price of others may also be rational, at least if the goods are auctioned off at single occasions. Once other participants realise that someone follows this strategy, and under repeated auctions, there is a risk for revenge, i.e. that others will do the same. Bidding dominated bids is (mostly) not rational, while it may be rational not to bid up to redemption value. This is so if an individual during initial bidding rounds sticks to a cautious strategy and finds out that the current high bid exceeds the own redemption value.

73 Table 5 analyses properties of the final allocations while not of the process leading up to the results. Column 2 gives the number of markets concluded during each experiment and the total number of bids during the experiment: the final allocation of each market

includes 6 individuals' bids for 8 projects. The third column indicates the share of final bids that could have been raised and further improved results for the individual; experiment 1 for example had 7 such bids out of 480 (1%) while experiment 10 had 7 out of 432 (2%). The predominant behaviour is thus such that final allocations see few unrealised potential profits. Closer scrutiny of the results indicates that it primarily is the more complex conflicts that now and again makes it difficult for subjects to realise that it is worthwhile to raise bids further. We therefore have

74 Result 3: Final allocations are typically Nash equilibria.

75 The next two columns point to the share of bids above redemption values. A dominated bid makes the bidder run the risk of loosing money, but, as pointed out above, there will be no loss if it is the individual with the highest redemption value that bids the dominated bid while the others stop at or below their redemption values. A dominated bid however typically indicates that the bidder does not understand the incentives of the game.

76 Dominated neutral bids do not affect the profit of the bidder but shrink that of others. Column five indicates that this behaviour is widespread. To bid dominated neutral bids repeatedly indicates that the bidder has realised the logic of the game. Result records moreover indicate that it typically is one or two individuals that bid dominated neutral bids for many projects during each experiment.

77 The last column gives realised as compared to potential earnings; the latter is the aggregate income if $b_i(x^k)=V_i(x^k)\ \forall i,k$. No clear correlation between earnings and bidding strategy can be observed. This is partly the consequence of that single individuals that make single major mistakes--place a dominated bid--is more important for the financial outcome than is the average bidding strategy.

78 Finally a few comments on the four failed experiments. Experiments 13 and 15 were prematurely terminated since in each, one subject failed to understand the mechanism. So would also experiment 14 have been, had it not been for a computer failure coming in-between. Poor understanding manifested itself in that the subject kept on bidding although this generated losses. The ascending bid-adjustment rule put a natural end to the experiments in that the five subjects that did understand the mechanism stopped from raising their bids in order to avoid losses.

79 The reason for the problems was probably that 'subject quality' this summer week was different to previous periods. These students may have required more extensive training than previous groups. A competing hypothesis is that the specific type of complexity (complementarity in redemption values) introduced for these trials was too difficult to handle. This is refuted by the observation that complementarities were successively solved during experiment 16.

80 Experiment 8 made use of the tatonnement-like price adjustment rule. It generated no successfully concluded market. The reason was that one subject failed to understand the mechanism and out of utter frustration kept changing bids over and over again. Our initial interpretation was that the tatonnement-like bidding adds too much complexity to

the market; while ascending bid adjustment has a 'natural' end of bid adjustment in the subjects' redemption values, no such feature is inherent in the tatonnement approach. Since also experiments 7 and 16 made use of tatonnement price adjustment and were successful, the problems during experiment 8 were most probably again a result of a single individual that understood principles poorly.

Summary

81 Section 4 has reported on a series of experiments designed to control for incentive aspects of a proposed mechanism to allocate track capacity. For 12 out of 16 experiments the mechanism generates solutions that are close to economically efficient. Mechanism solutions are moreover on average superior to a benchmark allocation. Two classes of anomalies have been detected. First, the process is vulnerable to participants that have problems to grasp the incentives of the auction. Secondly, repeated cases of subjects bidding up the price of competitors in order to stop them from making too much money have been observed; the risk for such behaviour was, in fact, observed already in the original Vickrey paper (Vickrey 1961, p 22).

82 It takes time for individuals to realise the logic of a second price auction. Much effort has therefore been directed to training sessions. Results indicate that there are at least two types of subjects. First, a few individuals have major problems to understand incentives and realise little of their potential earnings. Moreover, by bidding above their own redemption value they get projects that 'should' have been allocated to others, thereby undermining profits for all. Secondly, there are subjects that understand the incentives so well that they even can engage themselves in bidding that deliberately reduce profits of others. The overall conclusion is however one of robustness; although observed behaviour both indicates poor understanding of some and 'mean bidding' of others, the mechanism still generates highly efficient allocations.

83 The paper reports only on a very first test of the mechanism, applied to a set of conflicts that may be restricted if compared to contests generated in a real application. More research has to look into other classes of conflicts and to see if these generate problems that limit the applicability of the mechanism. Both more complex block-internal trade-offs of the sort modelled here and problems arising with routes over more 'normal', multi-block railway lines must be scrutinised. An ideal development programme of the mechanism is to think of the present set of trials as part of a first development stage, namely that of desk trial of principles. Before it is meaningful to proceed to a second stage, involving more complex cases with subjects that know the industry from inside, it is, however, relevant to continue experiments in 'pure' laboratory settings.

VERTICAL UNBUNDLING IN THE RAILWAY INDUSTRY

84 The paper has reported on trials to develop efficient tools for time-tabling in a context with one infrastructure manager and several independent operators of railway services. But the order of the day in the industry is one of vertical integration. So what's the industrial organisation rationale for choice between these different organisational structures?

85 Without going into formal modelling, think of the following simple framework to provide support for the intuition. As before, there is one manager of infrastructure access (player 0), selling an intermediate good x (track access), used by i=1,...,I independent, downstream train operators. To simplify, x here belongs to a compact, convex and non empty set $X \subset \Re_n$. This setting exactly corresponds to the relationship between downstream functional entities (for instance a Freight and Passenger Division etc.) of a 'standard' type, vertically integrated railway firm and its scheduling department; cf. Harker&Hong 1994 for related discussion of the monolithic firm case.

86 Track access is combined with a vector of other inputs (y), competitively supplied by other industries at price m; y includes rolling stock, personnel etc. Operator effort (e_i) is required in the production process. It is here related to the toil expended by each to stick to the routes allocated during the time-tabling process. An operator that does not 'hit the route' assigned to him may infringe on the routes of others. On high-density lines, a disturbance can spread fast and may cause severe losses to others than the party inducing the problem.

87 Effort is a moral hazard problem since it cannot be perfectly monitored and enforced. It is a horizontal-relations problem since it is less of a dilemma for the infrastructure manager and more for other operators that may be hurt by disruptions generated by the first. We therefore write operator revenue as $R_i(x_i,y_i,e_i;\, e_{-i},\theta_i)$. The (adverse selection) 'type' parameter θ_i, i=1,...,I depicts profitability of operators and their single routes.

88 The operator's utility $U_i(I_i,\, e;\, \theta_i)$, depends on his net income, I, and his and others level of effort; it is contingent on the operator characteristic. $P_i(x_i,y_i,\theta_i;\Psi)$ denotes the payment made by the operator to the infrastructure manager for getting access to track; $\delta P_i/\delta\Psi<0$, Ψ being an index for track capacity. The operator makes input choices to maximise expected utility. Let $x^*(P,\theta,\Psi)$, $y^*(P,\theta,\Psi)$ and $e^*(P,\theta,\Psi)$ denote the solution to

89 $$\max_{x,y,e} U\left[R(x_i,y_i,e_i;e_{-i},\theta_i)-P(x_i,y_i,e,\theta_i;\Psi)-my;\theta_i\right] \qquad [4]$$

90 Let $C(x,\Psi)$ be the total infrastructure cost, encompassing costs related to use and capacity expansion. Given the agent's choices, the allocation body earns

91 $$P\left[x^*(P,\theta,\Psi),y^*(P,\theta,\Psi),e^*(P,\theta,\Psi)\right]-C\left[x^*(P,\theta),\Psi\right] \qquad [5]$$

92 This analytical structure points to three important decisions on resource use that link operators and infrastructure manager together. First, the infrastructure manager decides on capacity investment in infrastructure, affecting P and the relative importance of e_i. Secondly, given the available infrastructure, the manager specifies a time-table which is decisive for what services that operators can offer the market. Third, the quality of operations depends on how loyal each party decides to be towards the routes allocated during the time-tabling process.

93 All three decisions are obviously fraught with asymmetric information problems. If the infrastructure manager has incomplete knowledge of the operator profitability of routes', adverse selection problems may generate operational but highly inefficient time-tables as well as incorrect decisions on track capacity expansion. If operators don't pay attention to the consequences to others of sticking to the time-table slots allocated during the process, moral hazard may generate operations that are notoriously late.

94 Our hypothesis is that railways have over the years integrated vertically in order to soften the blow of these incentives. While not absent in the monolithic railway firm, the strength of the incentives is reduced in that division management does not have to face competition in their own market segments. All managers are, moreover, parts of the same mother company and knows that 'bad behaviour' will be detrimental for that firm.

95 Other modes are not void of these incentives. The extent of interdependency is however much higher on railways since vehicles are stuck to the rails to a completely different extent than are road vehicle to roads or airplanes to airports. If this hypothesis is correct, a corollary is that development of new tools to deal with adverse selection and moral hazard problems in the industry may provide ground for vertical unbundling on purely commercial grounds, not as a state-directed initiative.

96 Tracking back to the discussion of choice between first- and second-price auctions it should be noted that the information generated by prices established during an auction can be used for purposes other than the (adverse selection) track-allocation task. One application is related to the risk of post-contractual opportunism. If some sort of defection charges could be used to curb moral hazard incentives, operators may be more prone to stick to the time-table slots allocated to them during the process. Charges based on information generated by a Vickrey mechanism may, moreover, be closer to real value-of-access/cost-of-disturbance that those based on first-price information. This information can, secondly, be used to make more informed investment decisions. While track capacity cannot be smoothly adjusted to demand, excess demand for access to a line will sooner or later induce capacity investment.

97 A word of caution towards uncritical use of willingness-to-pay reported by operators should finally be given. As pointed out by Borenstein (1988), profits of firms working under less-than-competitive conditions may under some circumstances provide incomplete information about the social value of an item, here the route over a network. This is so since if operators with monopoly control over different segments of the markets bid, the outcome may be less than optimal in the aggregate. While this observation is relevant, it is equally important to be aware of what point of comparison that is being used when the merits of a mechanism is discussed. Taking the allocation techniques of today as the benchmark, the proposed method may create vastly more efficient solutions, although it is not capable to capture intra-marginal benefits and costs in a perfect way.

CONCLUSIONS

98 The present paper has reported on a series of experiments, the purpose of which are to control for incentive aspects of a proposed mechanism to allocate track capacity. To summarise results in brief, one can say that most trials have been highly successful. Much laboratory work however remains to be done before it is time to call in men from the industry for applied testing.

99 The in-depth assessment of incentive aspects of a specific mechanism, and also the technical/mathematical problems with finding feasible solutions are two important aspects of this process. As suggested by Ledyard (1993), the *political viability* problem can be of equal importance in cases where extensive change of present institutions is part of a new mechanism. It may not be sufficient to demonstrate that the mechanism has appealing incentive qualities and that there are ways to deal with technical complexity; in addition, implementation requires a 'fair' spread of the benefits of the method, and in particular that a new way of doing things has no obvious looser.

100 It is therefore interesting to note that in Sweden old vested interests in the shape of the incumbent monopolist operator has fought railway-sector reform. None the less, the spring-1994 Government pushed a Bill through Parliament that would open up for on-the-tracks competition from 1995. In this text, while prescribing the use of administrative allocation principles as a start, the Minister endorsed the development of track allocation techniques making use of some type of pricing scheme. The Deregulation Act has, however, not survived the fall-1994 general election change of majority. The new government has postponed the deregulation and intends to undertake a thorough review of the sector reform of 1988 before taking a final stand on if, when and how to deregulate railways.

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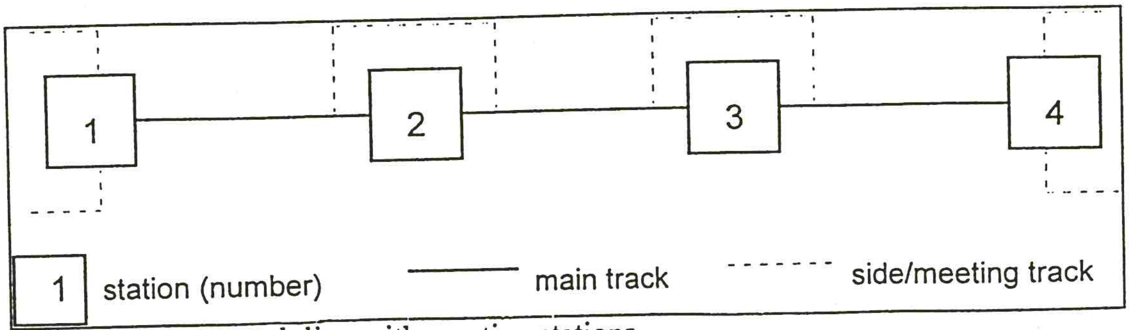
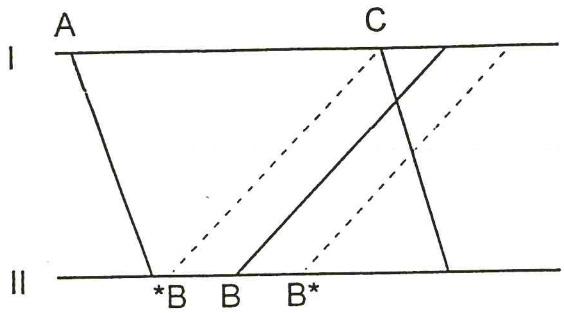


Figure 1: Single-track line with meeting stations.



A	B	C
(i) 2319	(ii) 1856	(iii) 2220
(iii) 1678	(iii) 1655	(i) 1112
(ii) 1120	(i) 920	(ii) 802

Figure 2: Stylised string diagram example with three routes (A, B, C) between two adjacent stations and with operators (i-iii) value-of-access.

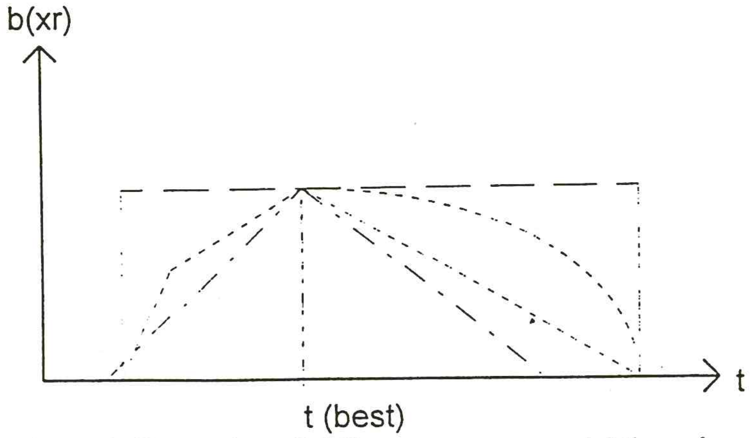


Figure 3: Examples of different ways to model the value of track access as a function of departure time.

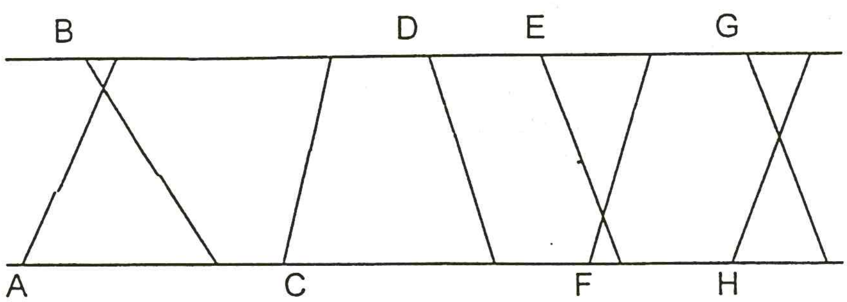


Figure 4a: Pairwise conflicts.

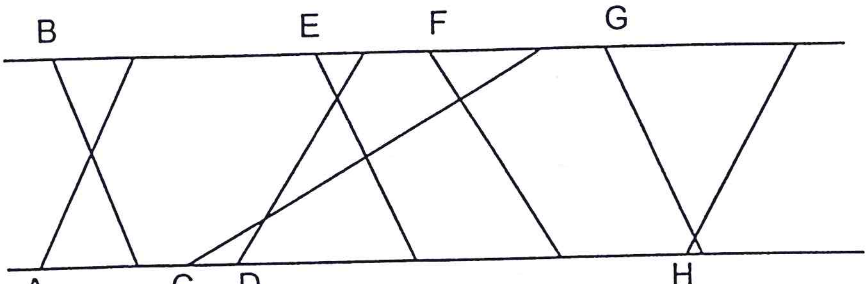


Figure 4b: Multi-route conflicts.

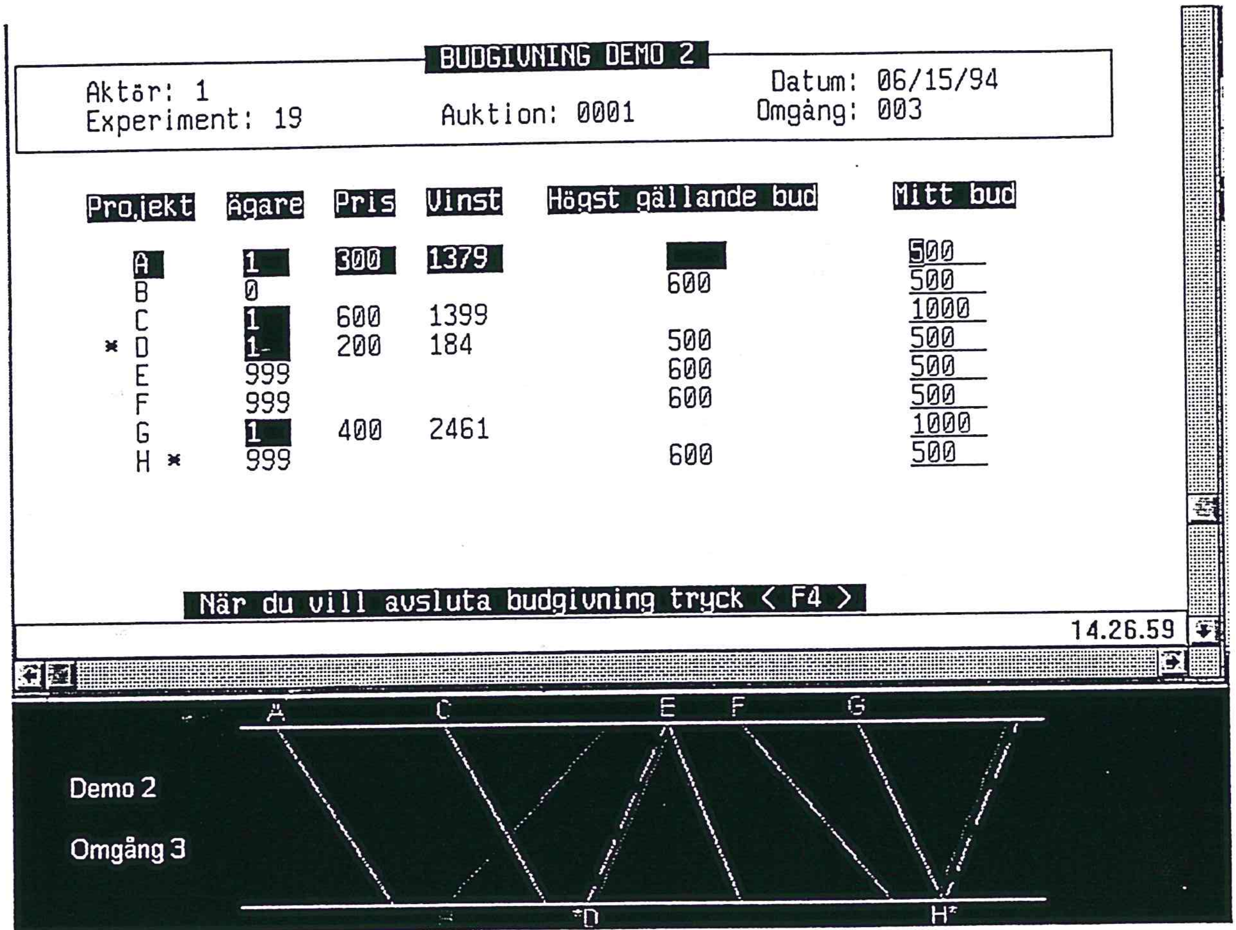


Figure A1: The screen as seen by experiment subjects. Legend; 'Aktör' - subject no.; 'Omgång' - bidding round; 'Projekt' - project/route; 'Ägare' - (current) owner; 'Pris' - (current) price; 'Vinst' - (current) profit; 'Högst gällande bud' - current high bid; 'Mitt bud' - my bid. 'Ägare 0' indicates that a route is not operated given the bids that have been submitted, and 'Ägare 999' is the computer.

Proj.	Individual no.					
	1	2	3	4	5	6
A	490	141	<u>2155</u>	1649	1726	**1901**
B	1423	1536	157	1202	**1898**	<u>1987</u>
C	845	**1206**	817	<u>2085</u>	663	777
D	<u>2737</u>	991	2363	**2378**	1222	2255
E	695	**2729**	2297	1283	<u>2778</u>	304
F	1984	<u>2891</u>	1653	1349	395	**2286**
G	450	679	1595	1111	**2339**	<u>2612</u>
H	1991	343	1050	**2032**	<u>2600</u>	1927

<u>Table 1</u>: Redemption values of experiment 6, auction 6. <u>Highest</u> and **second-highest value.**

	The value maximising allocation			
Proj.	Owner	Price	Profit	Redemp value
A	3	1930	225	2155
B*	6	1265	60	1325
C	4	1202	879	2085
D	1	2378	359	2737
*E	5	1819	33	1852
F	2	2450	441	2891
G	6	2600	12	2612
H	0			
Sum				15657

<u>Table 2a</u>: Allocation at $b_i = V_i$, $\forall$ i,k of experiment 6, auction 6.

Project	High bid (bidder)	Second-high bid (bidder)	Price	Profit	Redemp. value
A	2155 (3)	2000 (6)	2003	152	2155
B*	2010 (6)	1898 (5)	1265	60	1325
C	1210 (4)	1206 (2)	1206	879	2085
D	2971 (1)	2400 (6)	2400	337	2737
E	2778 (5)	2729 (2)	2729	49	2778
F*	2200 (6)	500 (2)	333	1191	1524
G	2600 (6)	2537 (5)	2600	12	2612
H	2600 (5)	2300 (1)			
Sum					15216

Table 2b: Actual allocation of experiment 6, auction 6.

Exper. no.	Market no. 1	2	3	4	5	6	7	8	9	10	Average
1	100	96,3	100	100	99,9	99,6	99,1	98,5	100	100	99
2	98,2	92,4	96,9	91,8	93,7	91,8	97,7	100	100	86	95
3	96,1	99,6	91,4	95,8	99,7	#					97
4	97,7	99	100	98,3	100	100	99,7	100			99
5	96	94,6	98,1	95,9	99,6	100	100	99,7	100		98
6	99,5	100	99,2	94,9	100	97,2	97,3	100	100	100	99
7	99,1	100	99,2	100	99,9	100	100				100
8	no results										
9	100	98,8	100	98,6	100	99,3	100	99,9			100
10	88	99,3	96.6	100	93	99,7	98,9	100	95		97
11	93	97,7	100	93,5	81,3	100	98,9	99,9	100		96
12	96,4	89,6	98,3	65,1	98,7	98,7	94,3	97,3	100	100	94
13	66,9	88,2	96,3	terminated							
14	#										
15	67,3	94,1	terminated								
16	100	99,9	98,1	99,7	##	##	100	##	##	100	100

Table 3: Efficiency results of experiments; percentage of potential redemption value that is actually achieved. #Terminated because of computer failure. ## The whole experiment was successfully concluded but results partially erased due to computer failure.

Exper. no.	Observed efficiency, %	Benchmark efficiency, % n=2	n=4	n=6
1	99(10)	86	95	98
2	95(10)	87	96	98
3	97(5)	84	95	98
4	99(8)	86	96	98
5	98(9)	86	97	98
6	99(10)	85	95	99
7	100(7)	86	96	99
9	100(8)	85	97	98
10	97(9)	77	88	92
11	96(9)	79	88	91
12	94(10)	77	89	89
16	100(6)	84	94	96

Table 4: Average efficiency of experiments as compared to benchmark solution with n=2,4 and 6 priority groups; percentage of potential redemption value that is actually achieved. Number in parenthesis indicates no. of markets in each experiment.

Exper. no.	No. of markets/bids	Non-realised pivotal bids, %	Dominated bids, %	Dominated neutral bids, %	Realised/ potential earnings, %
1	10/480	1	<1	8	97
2	10/480	1	4	10	25
3	5/240	4	2	3	93
4	8/384	1	1	1	132
5	9/432	2	1	15	51
6	10/480	1	1	2	129
7	7/336	3	<1	8	109
9	8/384	1	1	5	84
10	9/432	2	2	6	69
11	9/432	2	2	15	17
12	10/480	1	2	6	26

Table 5: Bidding strategy analysis; experiments 13-16 excluded.

1 Appendix A

2 Experiment Organisation

3 Each experiment lasted for about three hours, i.e. it was terminated had not all 10 markets been completed within this time. Subjects studying basic engineering, computer science and business administration were recruited from the local university college. Sessions included 6 subjects seated at a PC. A separate PC was used as bid collection hub, and all units were connected to a Unix system that handles the optimisation and send back data for graph construction. This link went down several times and generated the problems referred to in the presentation of results.

4 Subjects were trained in three ways. During Exercise 1, participants go through a guided drill, bidding for three private goods against the computer, and using the second price auction. Exercise 2 train subjects on second-price bidding against each other during two markets. Exercise 3 give a guided introduction to the Vickrey auction for interacting projects; a translation of the text is included in Appendix A. Emphasis is on making subjects aware of that projects have close substitutes.

5 A graphical display has been used to illustrate the nature of the conflicts (cf. Figure A1). On the top two-thirds of the computer screen a table with the eight projects A-H is displayed. Each participant see the price and profit pertaining to the project(s) allocated to him/her. For other projects, the current owner and his/her bid is disclosed. Using a string diagram, the lower third of the screen displays the graphical version of the solution. Using successively upgraded graphs emphasises that some routes are deleted to give priority to others while in other cases routes are forwarded/delayed in favour of each other. Deleted projects are in red, others in green, and a string is dashed if it is forwarded/delayed. Subjects are not informed about that graphs are related to railway problems.

6 The following experiments have been conducted:

7

8 Experiment 1-3. 8 routes with Figure 4a conflicts. Ascending bids. At this time, neither Exercise 1 and 2 nor graphics were yet included.

9 Experiment 4-6. The same conflicts but Exercise 1 and graphics added.

10 Experiment 7,8. Same conflict configuration as in experiments 1-6 but with tatonnement-type bidding. Also exercise 2 introduced.

11 Experiment 9. Same situation as experiments 4-6 except for that also Exercise 2 is included.

12 Experiment 10-12: 8 routes organised as indicated by Figure 4b.

13 Experiments 13-15. Conflicts between routes are the same as during experiments 1-6. Complementarity in redemption values between projects. During each market, three subjects have this complementarity between the same two projects, subjects and project shifting over markets. Redemption values are moreover generated so that if a subject has a bonus between A and F, someone else without a bonus is not given the high redemption value for A. This is to make sure that the first subject, preliminarily allocated A, bidding above redemption value of F and winning the latter will not loose A to another subject during a later round, thereby making a net loss on bidding above the F redemp-

tion value. In other words, values were constructed so that it is always optimal to try to bid above redemption value of F.

14 Experiment 16. Experienced subjects bidding for conflicting projects of the same sort as during Experiments 13-15 but with tatonnement-like price adjustment. An additional experiment no. 17, with the same outline as experiment 16, was prepared but had to be cancelled due to total break-down of links to the Unix computor.

15 Appendix B

16 Instructions to Exercise 3

INSTRUCTIONS

17 You will participate in a series of experiments in the guise of 'games' related to economic decision making. If you read instructions carefully and take appropriate decisions you can make a considerable amount of money. The compensation will be paid to you in the form of value checks as soon as we're finished.

THE AUCTION

18 In the same way as during previous exercises you participate in an auction; what is sold is called project A, project B etc... You shall during the experiment try to buy projects by submitting bids. A project is sold to the highest bidder. Its *price* is related to the second highest bid on the project. *The value* to you of buying a project, the redemption value, is indicated on the auction list given to you before each experiment. The attached sample auction list includes the following values: A - 1679, B - 1652, C - 1999, D - 576, E - 1192, F - 633, G - 2861, H - 2317. Your *profit* is the difference between the redemption value and the price that you have to pay.

19

20 All numbers are in the currency dublons (db); you have to pay 10 db for each krona. After the experiments your profit will be converted from dublons to kronor.

21 **Example 1**: Your redemption value for A is 1679, you bid 1500 and you get the project. Another person bids 1400. You therefore pay 1400 and your profit is (1679-1400=) 279 db.

22 An auction list indicating your redemption values is distributed before each of the 10 experiments. The redemption value is your own private information - do not show the list to anyone.

CONFLICTS AND COMPLEMENTARITIES BETWEEN PROJECTS

23 The projects sold do not look in the way the initial example indicated. Projects are to a certain extent dependent of each other. The following instructions and exercises describe these interdependencies.

24 All projects cannot be implemented: If two projects can not be implemented at the same time this is illustrated using crossing lines in a simple figure.

25 **Exercise**: Enter the demonstration programme Demo 2. A picture showing projects A-H is now displayed. As you can see, there are conflicts between projects B and C, D and E as well as between G and H. We leave the exercise for now; leave the window as it is.

26 Projects can be adjusted or deleted: Conflicts between two projects can be handled (i) by moving one project and leaving the other in its original shape or (ii) by deleting one

project completely. In the figure, the 'change' option means that a project is moved to the right or left. Projects that are not undertaken are showed with red colour.

27 **Exercise**: Enter the bid 500 db for each of projects A-H and hit F4. The upper window shows (i) which projects that you have been allocated and (ii) how much you have to pay for these as well as (iii) the top bid on projects that you don't 'own' right now. In the lower window it is demonstrated which projects that are implemented at current bids.

28 Let us take a closer look at how the computer has solved two of the conflicts. B and C can not be implemented simultaneously. The bids that have been entered resulted in an allocation where the computer gets B while no-one is allocated C. The G/H conflict is solved by giving you an adjusted version of G while the computer gets H.

29 Enter the bid 1000 on project C and 1000 on project G (you 'own' *G but G is worth more to you) but nothing on others; hit F4. You have now been allocated project C while B is killed. You also have project G while the computer has H* rather than H as before. We leave the exercise for now; leave the window as it is.

30 Redemption values are reduced if projects are adjusted: For projects that are pushed or pulled, you will not receive the redemption value as given on the auction list but a smaller amount. The following rule governs the re-calculation: If the project is adjusted and gets a * before or after the project letter the redemption value is reduced by 1/3.

31 **Example 2**: Redemption value for H is 2317. If the auction gives you *H (or H*) the redemption value is adjusted to (2317-1/3*2317=) 1544.

32 ...and so is your bid and profit.: If a project that you have submitted a bid on is pushed or pulled your bid will be adjusted also. The re-calculation is performed in the same way as when the redemption value is adjusted.

33 **Example 3**: Your bid on H is 900. You are allocated *H (or H*). Your bid is therefore understood to be (900-1/3*900=) 600. Consequently, your profit of being allocated *H is (1544-600=) 944.

34 **Exercise**: To see how the 'adjustment' of redemption values work, do the following. Enter your redemption value as given by the auction list for each project; hit F4.

35 Identify how much you have to pay for the project(s) you have been allocated and which bids that you would have to submit in order to get the other project(s). Take a closer look at project D. Your bid was 576 db and you have now been allocated *D. Your bid is therefore understood to be (576-1/3*576=) 384. Since the price is low you earn some money of being allocated also the adjusted project.

36 Conclude the exercise: Hit F4. Observe what has happened since your opponent has 'reacted' on your bids. Note that, in order to get projects that you don't own right now, you would have to bid over your redemption values and thereby risk making a loss. Hit F4 again (two F4 without bids in-between is understood as you being content with the

result). Note your profit from the experiment on the auction list. You can see that the computer assists you to calculate the profit after each exercise, also for the 'adjusted' projects. Finish the Demo 2 exercise by hitting F4.

PROGRAMMING OF THE COMPUTER

37 The highest bidder has to pay a price that corresponds to **the second highest bid** on the project. If you are allocated a project that implies that another project is pushed off its ideal form or if another project is altogether deleted you pay **a price that corresponds to the benefit reduction** resulting from your bid.

38 Each auction result in a solution of conflicts as well as a decision of who gets which project. **The computer is programmed to find that allocation of projects between individuals, and that project design that maximise total benefit.** 'Total benefit' is defined as the sum of submitted bids.

39 These qualities of the program have been illustrated with some simple examples above. Before starting with the 'real' auctions you will now perform some additional exercises to get used to the principles of the auction.

40 To do this, open Demo auction 2 and imagine the following situation. You are given an auction list (enclosed). <u>You must now make up your mind on which bids to submit</u>. Run through the following steps.

41 Take a look at the auction list; from the column 'Redemption value' you can se what you get if you are allocated each project. Decide on which bid to place during the first round. **Note**: If you enter a bid higher than your redemption value and if this means that you are allocated that project you will make a 'loss'. The amount will be subtracted from your other earnings. Hit F4.

42 The computer calculates who gets which projects, if the project is adjusted or if some project is altogether deleted. If you want to raise your bid for one or more of the projects, enter the new bids and hit F4. **Note 1**: You can only raise bids, not lower them. **Note 2**: You don't have to change bids on all projects, only on those that you wish to pay more for. **Note 3**: If you don't want to raise any bid, hit F4.

43 The computer gives you a new allocation of projects and a new set of prices; you can submit new bids. The bidding goes on until everyone is satisfied. This happens when no-one (i.e. neither you nor someone of the other participants/the computer) enters a new bid.

44 Observe who won which project, what price is to be paid for each and - for the projects that you won - the 'adjusted' redemption value (if any; this latter number is just displayed to yourself). <u>Note on your auction list</u> (a) the price of the project that you are allocated, (b) your 'adjusted' redemption value and (c) your profit from the round. Finally, during the 'real' auction you must add this profit to the profit of previous rounds (except for during round 1).

45 You can run new demos by hitting F4 and go into Demo2 again. Continue to do this until you feel reasonably comfortable and prepared to start the 'real' bidding. Check for instance what might happened if you place bids above your redemption values.

SUMMARY

46 The 'auction' that we are performing has the following features: You enter on the screen how much you are willing to pay for each of a number of 'projects'. The highest bidder can buy each project unless it has been deleted during the process. The price that you have to pay is a function of the bids submitted during the process. Your profit is the difference between the auction price and the redemption value.

47 Projects are to a certain extent mutually dependent. This means that you in certain situations are allocated projects that are slightly different and somewhat less worth than the one(s) that you have bid for.

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[i] Nilsson (forthcoming) has more on the Swedish reform, while Nash (1993) and Ludwig (1993) reviews the Brittish and German reforms, respectively. CEC (1991) is the EC directive.

[ii] Operators compile time-tables in the form of several hundred pages of graphical sheets detailing the strings for each (planned) service.

[iii] In order to compute this set of R prices, R+1 expressions must be optimised, i.e. one optimisation where each route has been excluded plus the all-inclusive optimisation. Furthermore, the R derivative values $B^{-\rho}$ have to be calculated.

[iv] The New Zealand second price auction of spectrum rights that generated very low prices would thus be a success in the Swedish context; cf. McMillan (1994).

[v] Plott (1994) gives an introduction to the testbed concept and the use of experimental techniques to to provide 'proof of principle' of the way that mechanisms work.

[vi] Corresponds to about US$44 in summer 1994.

[vii] The inverse of this value complementarity is a negative dependency between projects. Future experimenting could address this by defining certain deductions from redemption values to handle the impact of close-substitute competitors on one subjects' profits; the value of (say) A to subject i is 300 *lower* if subject j is allocated (say) F.

[viii] Trains are classified according to nature of service: High-speed passenger services, other long distance passenger services, commuter trains, carload freight trains, direct freight trains (no shunting between departure and arrival station), combined freight (piggy-back, containers) etc.

[ix] The present section takes the analytical framework proposed by Brewer&Plott (1994) as a point of departure.