Application of experimental economics in transport and logistics

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Abstract

There is scope for applying experimental economics in transport and logistics analysis. Experimental economics is a set of techniques for gathering (and analysing) data by inducing people (through specific rewards) to act as economic agents and observing the choices they then make in experimental situations. These experiments often involve interactions between the respondents, possibly in a market setting, and this can be applied in transport to study for instance shipper – carrier interaction. Various subfields of experimental economics that might be relevant for transport and logistics research are described. We also review past applications of experimental economics in transport and logistics and work out some ideas for future applications.

Keywords: experimental economics, logistics, transport, auctions, games

1. INTRODUCTION

Experimental economics (EE) is a branch of economics that started in the late 1940s (but only became popular many years later) and centres around the use of laboratory experiments in which subjects, through some reward medium (usually cash) are induced to behave as economic agents. The main (but not the only) difference between EE and a stated preference survey is that in EE the reward mechanism is used to have respondents make choices according to the institutional rules of the experiment instead of according to his/her own 'innate' characteristics (Friedman and Sunder, 1994). Mildly exaggerating one can say that SP respondents give their own preferences whereas participants in EE play someone else.

So far, EE has hardly been used in transport research. Nevertheless there are reasons why EE can fruitfully be applied in analysing transport, since it studies interactions between several decision-makers (in freight transport these could be

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shippers, carriers, drivers, third and fourth-party logistics providers) and can provide data on market decisions which usually remain confidential.

In this paper we work out the parts of experimental economics theory that appear most relevant for application in freight transport, focussing on market experiments to search for empirical regularities. We also provide a review of the past applications of EE in transport and logistics. Finally, the design of potential future transport and logistics experiments will be presented to analyse institutional settings (cooperation and information exchange) that lead to efficient transport solutions (minimising vehicle kilometres) while avoiding excess profits.

2. RATIONALE FOR APPLICATION OF EE IN (FREIGHT) TRANSPORT

The use of EE in transport, and especially in analysing freight transport, has considerable appeal. Two of the problems that freight modellers have to face are that for each shipment there can be several decision-makers (shippers, carriers, drivers, third and fourth-party logistics providers) and that data (especially at the level of the individual firm) are scarce. EE could help in solving both problems: it can be used to study situations with several interacting players (in a market and/or game-theoretic setting) and it can provide behaviourally rich data on commercial decisions for which data are usually not available (as in Holguin-Veras and Thorson, 2003). Especially market experiments could be particularly useful in freight transport, because many of the outcomes in freight transport are determined on markets (e.g. the freight rates that shippers pay for the services of the carriers). In passenger transport, the label 'market' is also sometimes used, mostly for situations in which it is hard to say who the consumers and suppliers are, or even what the commodity is, and where there is no equilibrium in price units (but possibly an equilibrium mechanism in terms of travel times). Exceptions are roads for which a supplier of road-space charges a price (e.g. private toll-roads) and public transport, where transport services are sold for a fare, and the operators in some countries are competing for corridors or slots. However there is little need for applying laboratory experiments in public transport, certainly in the UK, since there is plenty of field experimentation going on.

Davis and Holt (1993) list three types of applications of EE:

- Market experiments, in which the predictions of economic theory on market forms and price determination can be tested (e.g. perfect competition, oligopoly).
- Game experiments, in which the behavioural implications of specific games (prisoners' dilemma, sequential bargaining) are tested.
- Individual decision-making experiments, where the axioms of expected utility theory under uncertainty are investigated.

If one moves from the first to the third type of experiment, the environment becomes simpler. In market experiments, researchers have tried to capture essential characteristics of natural markets. This complexity is reduced in game experiments and in individual experiments there is no longer a dependence on the actions of other agents. These areas can overlap to some degree; markets are now often studied in a game-theoretic context (e.g. Cournot-Nash equilibrium).

Individual choice experiments in EE usually are about a choice between different lotteries, seeking to investigate whether the choices are consistent with expected utility theory or not. This could be relevant for transport studies that include decision making at multiple periods (e.g. maximising lifetime utility), but will not help to solve

the specific multi-actor interaction and missing data problems in freight transport. In the remainder of this paper we shall focus on market experiments. The market experiments in freight transport can be studied in a game-theoretic setting (as Holguin-Veras and Thorson did), but other (non-market) game theory seems less relevant here.

Another typology of experiments in EE from Davis and Holt (1993) is the following:

- Experiments to test behavioural hypotheses. The laboratory experiment is set up to satisfy several structural assumptions of a particular (economic) theory, and the behavioural implications are then compared with the predictions of the theory.
- Experiments for theory stress tests. If the initial laboratory tests do not lead to a rejection of the theory, then it can be tested whether relaxing the assumptions underlying the theory (increasing realism) will change the outcomes.
- Experiments searching for empirical regularities. For instance when information on costs or discounts given is confidential, EE can be used to derive 'stylized facts' on the relations between variables.

The third type of experiment in fact addresses the missing data problem that occurs so often in freight transport too, as was mentioned above. The issue in such situations is that of 'design parallelism' (Davis and Holt, 1993, p. 31): how closely should the laboratory experiment resemble the natural situation? Some early experimentalists tried to use laboratory experiments to measure behavioural parameters, by closely mimicking some natural market institution and environment. By now, the majority view in EE seems to be that this is not a useful goal of EE (Friedman and Sunder, 1994, p. 9), since these parameters vary with the institution and the environment, raising questions of external validity of the experimental outcomes. So in the design of an laboratory experiment maximum realism is not the issue; effective designs are often quite simple compared to reality or even compared to formal models, but contain the essential information to answer specific research questions (as the ones above). Nevertheless, experiments that are targeted to learn something about reality and do not strictly refer to a specific theory (e.g. because theory has not been worked out) can be very worth while to increase our understanding about certain phenomena, provided that the experiments are not just 'shots in the dark', but set up with ideas on the expected data patterns in mind (Davis and Holt, 1993, p. 514).

3. AUCTIONS

The type of EE experiment that appears most directly relevant for studying freight transport is the market experiment. Several market trading institutions have been investigated in EE (Davis and Holt, p. 35-44). The most relevant candidates (relevant because they capture key characteristics of actual market conditions) for freight transport analysis are the posted offer auction and the double auction. Both are discussed below.

3.1 The posted offer auction

The posted offer auction is an example of the Bertrand model of price competition in oligopoly situations (see for instance Davis and Holt, 1993). In this type of auction

sellers (in freight transport: the carriers supplying transport services to shippers) propose prices publicly, that is to all buyers (the shippers in freight transport) at the same time. The sellers not only select a price, but also a maximum quantity that they are willing and able to sell at that price (but this quantity is not posted). In the experiment the prices could be written on a blackboard or displayed on a computer screen. The buyers could be selected randomly from a waiting mode. Then the first buyer engages in as many transactions at the posted prices with sellers as he/she desires. After this, another buyer is selected at random and given a chance to buy. When all buyers have had this opportunity or when all sellers are sold out, the trading period stops. In the next trading period, the sellers can list new prices, etc. Publicly posted prices are used in practice in many retail markets, and carriers in some freight transport markets also behave according to the rules set by such an institution.

Many laboratory experiments with persons playing buyers in posted offer markets have resulted in buyers that are buying all units that are profitable for them in the trading period, starting from the cheapest offer and continuing until the price equals the unit value. Behaviour that follows such a straightforward rule can also easily be simulated on a computer, without the need to recruit subject for the buyers' roles.

Market power can be introduced in a posted offer experiment simply by changing the allocation of units to the sellers (large sellers that have an incentive to deviate from the competitive price versus small sellers). Mestelman and Welland (1991) have designed a posted-offer market experiment with advance production and inventories (as a mechanism to link the trading periods) versus production on demand, which may provide some points of leverage for experiments in transport and logistics.

3.2 The double auction

In the posted offer auction, the buyer has to make a 'take it or leave it' decision. This is an important asymmetry that can result in the seller reaping most of the surplus. In the double auction, there is more room for decision-making by the buyer, and the process of trading becomes sequential: in the experiment both buyers and seller can raise their hand and make public bids (buyers) and offers (sellers). In a trading period, the bids are raised and the offers lowered until the goods are sold (or a fixed amount of time has passed). After that, a new trading period starts, usually with the same initial endowments of unit values or costs to each buyer and seller. This is the trading institution that is used most in EE, after the pioneering work by Vernon Smith (Nobel Prize winner in Economics in 2002 for his contributions in EE) in the 1960s, who found a fast convergence to competitive prices when using this mechanism for many situations, including situations with very few agents. Smith argued that the double auction institution (with public information about the bids and offers) is a better representation of neoclassical price theory than decentralised negotiations between buyers and sellers. Posted offer market experiments have shown a convergence to competitive prices, usually a convergence from above, with a low efficiency in the early periods, whereas double auction experiments converge to competitive prices very quickly, either from above or below. This can be explained by the fact that there is more market power for the sellers in the posted offer markets (with rather passive buyers) than in the double auction (with active buyers). A double auction with one seller can still give competitive prices, but a posted offer auction with one seller will tend towards monopoly prices. In a duopoly, there is a tendency with posted offer prices towards collusive prices, but this has not been observed with three or more sellers.

Usually the same experiment is repeated a number of times with the same agents, giving several trading periods. At the beginning of the experiment, each seller is given an endowment of units to be sold at prices exceeding certain given costs (otherwise there will be no profit). The buyers are given a value for these units. They can only make a profit by buying the unit at a price below its value. In most experiments, several trading periods with the same endowments are done, so that the agents can learn the game and earn a reputation for being trustworthy (or not). A possible application would relate to urban distribution centres that rely on the sharing of facilities between different agents and where the sharing of information and building up of trust can be crucial. The outcomes of all the trading periods are studied, but those of the final periods within an experiment are regarded as crucial for the conclusions.

The double auction market has also been used to study the effect of alternative forms of automation (electronic markets; Davis and Holt, 1993, p. 126), and this could be used in freight transport to study different applications of e-commerce for transactions between members of a supply chain, shipper-carrier interaction and e-shopping by consumers. An example of the bidding rule in such a computerised laboratory experiment is to display publicly the highest bid and the lowest offer (and not show the other bids and offers), but to store other bids that do not reduce the spread in rank order. Once a transaction takes place, bids and offers are selected from this queue (according to the ranking: the highest remaining bid and lowest remaining offer) and these are then displayed.

Some element of market power can be introduced in the double auction experiment (a form of a theory stress test) by allowing large firms to withhold some units (in spite of the price posted). This could be tried out for freight transport experiments as well, besides the more common variation of the number of bidders and sellers. In reality, there could be more subtle forms of market power such as contracts with penalty clauses for failure to provide the promised good or external (institutional) factors that favour one logistic party over another.

Middlemen can be introduced (Davis and Holt, 1993, p. 156) that buy in period 1 and sell in period 2. For freight transport we would be thinking of somewhat different types of intermediaries, especially firms that consolidate shipments from several senders into full-truck loads (or full loads for other modes), and/or perform warehousing functions. The middlemen could also be producers that play a role between input sellers and output buyers (Davis and Holt, p. 158). In freight transport one might think of wholesalers that bridge the gap between producers and retailers.

3.3 Other auctions and games

The posted offer auction and the double auction are the trading institutions that are used most in EE, and that also appear most promising to capture the essence of price determination in freight transport markets. Experiments for both can be carried out without computers (with persons making a bid or offer raising their hand and an assistant noting offers and bids on a blackboard) and in computer laboratories (using standard EE or purpose-specific software). For some specific markets, other, less frequently studied, trading mechanisms could be relevant, such as the offer auction in which sellers can make offers sequentially (so they can lower their prices) and the buyers can accept or reject, or a clearinghouse auction in which the bids and offers are posted simultaneously and the price is determined at the point where the lines cross.

There is also considerable literature on experiments where the trading institution is bargaining (be it unstructured, structured, sequential, etc.). These experiments do not seem particularly relevant for freight transport analysis, as they involve how to split a fixed sum, whereas in the interactions between shippers and carriers the sum of the benefits (payoffs) often is not fixed. Auction mechanisms as they are used at real auctions (English auction, Dutch auction, etc.) are also less relevant for freight transport analysis. They deal with selling a single unusual item.

The issue of reputation is sometimes studied in EE, and this might bear on freight transport, where (some) carriers also try to build up a reputation with the shippers. Reputation is related to information asymmetries: the sellers know the good or service they are selling, but the buyers have to wait and see what the quality will be. In single period games, this could result in sellers delivering low quality (the 'lemon' problem, Akerlof, 1970), but over time sellers may invest in building up a reputation for high quality. Laboratory experiments have shown that this only happens when buyers and sellers interact a sufficient number of times.

4. SP EXPERIMENTS VERSUS EE

The main difference between EE and a stated preference (SP) survey is that in EE the reward mechanism ('salient rewards') is used to have respondents make economic choices. Salient rewards are rewards for the subjects in the experiment that depend on the actions of the subject (and possibly those of others), more specifically of the subject behaving according to the institutional rules of the experiments instead of according to his/her own 'innate' characteristics (Friedman and Sunder, 1994, p. 13). An example is a reward that is proportional to the profit made by the subject in a market game. EE and SP surveys have in common that the researcher has control over the conditions in the experiment.

Researchers in EE call the way they deal with preferences 'induced preferences', because of the way they offer salient rewards to the subjects. In SP and contingent valuation, respondents are asked to elicit their preferences. But both ideas can be combined: SP and CV surveys can include real incentives (in a competitive auction format) for the respondents, not to behave according to some pre-specified rules as in EE, but to state their true monetary value for some good. This has been shown to reduce the difference between willingness to pay and willingness to accept outcomes for the same good, a problem that has been hampering contingent valuation studies for some time (Coursey et al. 1987, also see Plott and Zeiler, 2005 on framing effects in EE, and Carlsson and Martinsson, 2001 on the external validity of SP outcomes).

Other differences between EE and SP are that many applications of EE study (simplified) markets or other game-situations, focussing on aggregate (e.g. market) outcomes) where agents interact with each other, whereas most SP applications ignore market structures and interactions and study behaviour of isolated individuals, to derive models for the relative importance of various attributes. However there are exceptions: individual-level EE for decision-making under uncertainty and interactive SP (see section 6). Both EE and SP usually start from the assumption of a utility or profit function, and utility or profit maximisation, which is then tested or used as theoretical foundation for a choice model.

Many of the design issues in EE are similar to those in SP. Also in EE, methods such as paired designs, blocking, fractional factorial design and Latin square are use (Friedman and Sunder, 1994, chapter 3; Davis and Holt, 1993, section 9.4).

5. METHODS OF ANALYSIS IN EE

The methods of analysis of EE data are often relatively simple: graphical analyses of price convergence between trading periods are frequently carried out, as well as standard statistical single-variable tests (binomial, Chi-square, t-test, Mann-Whitney). In some other applications, multiple variable techniques are employed, such as analysis of variance and regression analysis (Friedman and Sunder, chapter 7; Davis and Holt, section 9.5). Holguin-Veras and Thorson (2003) also used regression analysis to explain total profits and the total number of stops made by the carriers from the number of competitors, the total freight volume and the number of nodes to be served. More sophisticated econometric models are only rarely used on EE data. Panel data methods would seem appropriate (also mentioned by Davis and Holt, p. 528) if the same subjects make decisions in multiple time periods, as is the case for most applications of EE.

6. EXISTING APPLICATIONS OF EE IN TRANSPORT AND LOGISTICS

In transport analysis, individual choice theory has been applied extensively (though usually in the context of perfect knowledge of the decision-maker, not with uncertainty about the pay-offs). Game theory and market theory have also been used now and then, e.g. in the context of debates on deregulation (e.g. Preston, 1991) or network modelling (Friesz et al, 1985, Watling and Clark, 2002). However, to this author's knowledge there are only a few applications of EE in transport.

6.1 The agents are public authorities versus contractors

Isacsson and Nilsson (2003) performed experiments with students in Sweden on the allocation of rail track capacity to competing operators, extending earlier experiments on this issue in the late nineties. All participants played the role of buyers under several auctioning mechanisms. In Lunander and Nilsson (2004), experiments among students were carried out in the context of public procurement for road markings (renewing the paint) in Sweden. Here some 'large' bidders were given decreasing average costs and some 'small' bidders had increasing average costs. The focus of this paper was on combinatorial bidding: the bid for multiple units can differ from the sum of the individual bids.

6.2 The agents are end-users (travellers)

In passenger transport, Innozenti et al. (2009) carried out experiments on mode choice with 62 undergraduate students in Florence. The agents could select either metro or car (or bus versus car). If many choose car, there would be congestion and additional car travel time, so there is a dependence of the payoffs on the decisions of other agents. Similar experiments about congestion, but focussing on car drivers' route and/or departure time choice have been carried out by Selten et al. (2007) and Ziegelmeyer et al. (2008).

6.3 The agents are end users versus a public transport company

Denant-Boèmont and Hammiche (2009) carried out economic experiments with 240 students interacting in groups of fifteen, where one subject played a public transport operator choosing public transport capacity and fourteen subjects played travellers choosing car or public transport. These laboratory experiments reproduced the Downs-Thomson paradox which states that increasing road capacity, by causing shifts from public to private transport, to which the operator could react by raising the fares or reducing services, could lead to higher total transport costs.

6.4 The agents are managers of firms involved in logistics

The 'Beer Distribution Game' (see for example Sterman, 1989) can be regarded as an example of experimental economics in transport (or at least in inventory logistics). This game on inventory management, originally developed at MIT, has been used to introduce students and managers to the 'bullwhip' phenomenon (the further up in the supply chain, the stronger the amplification of changes in final demand). The game is played by several teams of four players each (retailer, wholesaler, distributor and manufacturer). Each player has to manage his own inventory of cases of beer. Retailers supply the consumers and order cases from the wholesaler, who orders from the distributor, who orders from the manufacturer. At each stage there are shipping and receiving delays. The game has been played at many universities, sometimes with a reward mechanism (the team with the lowest inventory plus stockout costs gets a financial reward). The results indicate very substantial overreactions to an increase in consumer demand. First effective inventories become negative and later on they become very large. The further away one gets from the consumer, the greater the variation in orders and inventories and the greater the time lags. This experiment does not contain price-setting, or consolidation issues in transport, it purely handles stock management.

One of very few examples of EE in freight transport itself is Holguin-Veras and Thorson (2003; also in Holguin-Veras et al., 2004) who had undergraduate students representing profit-maximising trucking companies. For given origins and given destinations (centroids) the students had to specify truck tours (consolidating shipments trying to get full truck loads). After that the (simulated) buyer gave the centroids to the lowest bidders. Finally the tours could be modified by the trucking companies. A somewhat unrealistic element in this experiment is that the trucking companies decide which origins will be combined with which destinations, in other words the deliveries of suppliers to their customers. In practice this decision will be made (in an earlier step) by the sender and/or the receiver. Decisions that could be part of the offers of the carriers are whether to transport the shipment directly from the sender to the receiver or to use an intermediate transshipment location (consolidation and distribution) and on the mode and route. Holguin-Veras and Thorson found a relatively good agreement between the parameters estimated on the experimental data and theoretical values, suggesting that "… the EE approach is able to capture, at least in part, some of the fundamental dynamics of the urban freight transportation process and that this approach has great potential in this area of research". Another application concerns the procurement of trucking services by a large logistics company in the U.S., by means of a combined-value auction (which allows carriers to bid for combinations of routes instead of individual routes only, to achieve higher load factors and fewer empty returns, Ledyard et al., 2002). A possible extension is discussed in section 7.1.

In Holguin-Veras et al. (2009), EE is used to study interactions of shippers and carriers on the choice of mode and shipment size. The paper discusses the theoretical and empirical evidence on the subject and concludes that freight mode choice can be best understood as the outcome of interactions between shippers and carriers, and that mode choice depends to a large extent on the shipment size that results from these interactions. Game theory predicts that under typical market conditions, the shipper and carrier will cooperate in decision-making about these choices. This hypothesis of cooperative behaviour was tested by economic experiments.

This was accomplished by conducting two sets of experiments:

- some with the shipper playing the lead role in selecting the shipment size;
- and others in which the shipment size decision was left to the carriers.

In each experiment, one player (e.g. a student) played the shipper, three players played the carriers competing against each other to provide transport services to the shipper. Both shippers and carriers were trying to maximize their profits. This behaviour was induced by giving prizes to the winning (most profitable) shipper and the winning carrier.

The protocol for the leading shipper experiment is given in Annex 1. The shipper moves first by deciding on the shipment size on the basis of his/her production cost function.

Each carrier has three modes: van, truck, and combined road/rail and subsequently prepares a bid based on what he/she thinks is the optimal mode for the job The shipper then selects the lowest bid The bidding process is repeated until the shipper is convinced he/she has found the optimal shipment size.

In the leading carrier experiment (also see the protocol in Annex 1) the shipper only provides information to the carriers on the total amount to be transported (the carriers can choose the shipment size, but each carrier can only use a single mode)

These experiments were carried out in the US, the UK and The Netherlands, mainly among university students.

The results from both experiments were compared against the results obtained numerically under the assumption of perfect cooperation of the shipper and carrier, i.e., the condition in which the participating companies are only concerned with the performance of the entire operation.

For the leading shipper case we found the same mode and shipment size/delivery frequency as the cooperative optimum solution, and more or less the same combined profits, in 23 out ot 26 experiments. The leading carrier experiments give the optimal (cooperative) solution for 16 out of 20 experiments.

These results clearly indicate that, in competitive markets, shippers and carriers are likely to cooperate in the selection of the shipment size and mode. Also, it really does not matter who "makes" the decision about the shipment size and mode to be used at a given time period, as over time the shipper—that is the customer—ends up selecting the bids more consistent with its own interest. These findings imply that assuming a sequential or an independent decision process is not correct. In other words, these results do not support the assumption that freight mode choice is solely made by the carriers. This has important implications for freight mode choice as the assumption of independence has been frequently used.

Hensher (2002) proposed stated choice experiments that include interactions between agents and described how discrete choice models can be extended to include interactions. This seems a very promising research direction, particularly for studying

decisions in supply chains. The experiments presented however differ from experiments as are commonly used in EE, certainly for market contexts (no reward mechanism, no market trading institutions such as the double auction), and were also not based on game theory.

Hensher's interactive agency choice experiments (IACE) and the econometric models for estimation on these choice data start from the type of experiments and models that are well-known in transport analysis, and then introduce new elements. These include sequential choices, where agents are informed about the previous choices of other agents, and correlation over alternatives and choice sets within and between agents. This is done for pairs of agents (e.g. shipper-carrier) and the process of feeding back information continues for all pairs where agreements have not been reached. Interactive choice experiments (not EE) have been carried out on telecommuting choices by employers and employees (Brewer and Hensher, 2000; Rose and Hensher, 2002), decision-making on travel within a family (Dellaert et al, 1998) and indeed on interaction between shippers and carriers (Hensher and Puckett, 2005).

A disadvantage of IACE is that the survey costs of interviewing shippers on the responses of the carriers etc. can be quite high (compared to more standard stated preference surveys) and that the resulting samples are small. This led to the development of minimum Information group inference, MIGI (Puckett and Hensher, 2006), where agents are interviewed only once, but the model not only includes each agent's standard utility function, each shipper is also matched with a carrier and their group decision making is inferred. This method has also been applied by Blomberg Stathopoulos (2009) for decision-making in a household on residential location among three members.

7. PROPOSALS FOR FURTHER APPLICATIONS OF EE IN FREIGHT TRANSPORT

Below, several experiments are proposed, each within a market setting. This means that the interactions on shipments between various agents in transport (senders, receivers, shippers, carriers) are studied as markets in which one group of agents acts as sellers and another group as buyers. These market settings could also be analysed in terms of game theory.

7.1 Transport experiments

It has been argued that to reduce the external effects from freight transport, one of the most promising measures is to increase the load factor and reduce the amount of empty driving by supplying information about shipments to be transported between firms, for instance through internet.

Both of these issues can be studied in an initial, simple experiment in which the carriers are given different costs for different shipments and the shippers are given different unit values for different shipments. This setup can then be used to compare the outcomes in terms of transaction prices between different institutions (especially double auction and posted offer auction) and different forms of information exchange between potential buyers and sellers. The research question here is which information on bids and offers (e.g. automatic information through the internet) is most useful and most needed to obtain efficient trading. This can help to design or regulate electronic

information exchange markets for freight shipments: which information should be exchanged here? Examples of information to be provided include: which amount needs to be transported from A to B? What are the prices the buyers are willing to pay (the bids)?What are the offers already received from sellers of transports services (or only the lowest offer)?

A considerably more complicated experiment in freight transport can be designed to shed light on the question which carrier will carry which shipments for which price. This could build on the work of Ledyard et al. (2002) and Holguin-Veras and Thorson (2003). The number of shipments (and the shipment size) is given, including their production and consumption pairs (for each shipment, both the production location and consumption location are known). The players are carriers that provide transport services to shippers. It is assumed that shippers do not carry out the transport themselves (i.e. own account transport), but this could be relaxed (and the importance of this relaxation tested) later on. The task for the carriers is to combine shipments (consolidation) at the production end, carry out long-haul transports and to distribute at the consumption end (or organise a direct transport from production to consumption), minimising costs. This task also includes returning the empty vehicles to their starting point. The shippers can be represented by other players, or simulated (just choosing the lowest bid). The rewards for the carriers should be based on the difference between the tariffs paid and their transport costs. Instead of just giving the carriers a cost, as in many EE applications (and the above simple experiment), the carriers have to solve a cost minimisation problem and the ones that are most successful in this will have the largest opportunities for selling their services. The outcomes are not only transaction prices and profits, but also vehicle tours, stops and vehicle miles driven. This more complicated experiment can be carried out as well for several institutions and several variants in terms of information exchange between shippers and carriers, to find the sensitivity to the type of institution and the information exchange that minimises costs and vehicle miles. Since many externalities (local and greenhouse gas emissions, noise, accidents, congestion) are positively correlated with vehicle miles, these kinds of experiments could provide insights in the effectiveness of various means to reduce the external costs of freight transport.

7.2 Logistics experiments

The focus of the transport experiments in section 7.1 is on agents solving pure transport problems (batching, routing). In freight transport there are also trade-offs between inventory costs and transport costs. Higher transport frequencies lead to higher transport costs, but smaller inventories. This was the topic in the shipment and mode choice experiments in Holguin-Veras et al. (2009).

The experiments in Holguin-Veras et al. (2009) could be extended in various ways. Aspects that clearly deserve further research involve the use of computer simulations of shipper-carrier considering stochasticity and uncertainty in shipment orders, and the role of volume-price contracts, among many other possibilities. One might also consider experiments that involve the behaviour of the receivers.

Alternatively, one could combine the shipper and carrier into one agent (especially given the outcomes mentioned) and focus on inventories at the consumption (including further processing of raw and intermediate products and retail) end. This can be represented as a game between receivers on the one hand and senders/shippers/carriers on the other hand. The receivers want to minimise the sum

of their inventory costs and the transport tariffs paid. The other side wants to minimise transport costs, but maximise revenues (that depend on the tariffs paid). Inventory cost considerations can be brought into the experiment by distinguishing multiple periods (e.g. with fluctuating demand) and inventory costs representing the costs of transferring goods from one period to the other. The final outcome depends on the distribution of market power between the two sides, and several variants for the distribution of market power can be tested. One variant could be factory-gate pricing (FGP), where the receiver (e.g. a large retailer) pays a price for the inputs exclusive of transport and organises the transports to its depots itself. This could reduce vehicle kilometres if there is sufficient scope for consolidation of flows from different suppliers and for combining flows to and from the depots into tours. Another variant is vendor-managed inventories (VDI), where a, generally large, supplier optimises transport and inventory logistics of the receivers of its goods.

Another variant of this logistics experiment would not start by imposing factory-gate pricing, but by investigating whether it would emerge from the decisions of the players in situations (spatial supply chain configurations) where FGP offers advantages (and would not in other situations). The key issue in FGP is whether only the flows from a supplier to a client are taken into account or the flows from several or all suppliers to a single client. A carrier could do jobs for a single supplier, but also be contracted by a supermarket to carry out transports from several suppliers to the supermarket. In this variant of the logistics experiment, several spatial supply chain configurations are compared and the players are trading transport services. In this experiment we assume that there are two supermarket chains, depicted by the big squares (one red and one yellow) in Figure 1. These supermarkets get their products from a number of suppliers indicated by small blue squares. These are different products: the suppliers are not direct competitors of each other. Both supermarkets are direct competitors. All suppliers deliver to both supermarkets (this assumption can easily be changed). We are assuming that the decisions of who will deliver to whom have already been taken (so there is no experiment on the selection of competing suppliers by the supermarkets). The deliveries of the suppliers are made to the regional distribution centres of the retailers. From these centres, the supermarkets send multi-product deliveries to their retail outlets (indicated by green dots; one supermarket chain has three outlets, the other has two). The transport cost functions are such that a higher vehicle fill rate, leads to lower unit transport costs. In the first picture, the supermarkets cannot organise the transport from their suppliers more efficiently than the individual supplier, so factory gate pricing is not useful. A supermarket cannot consolidate flows, but the individual suppliers might combine flows to both supermarkets. In the second picture, there is a lot of scope for consolidating flows from different suppliers to the distribution centres of the supermarkets; FGP is transport-efficient. In the third picture, FGP is an efficient solution, not just because the supermarkets can consolidate flows from different suppliers, but also because the supermarkets can design tours that combine deliveries to the distribution centres with deliveries to the retail outlets to reduce empty driving.

Figure 1. Spatial supply chain configuration. First picture: factory gate pricing (FGP) is not advantageous; second picture: FGP is advantageous because of consolidation of flows from different suppliers; third picture: FGP is advantageous because of consolidation and reduction of empty driving.
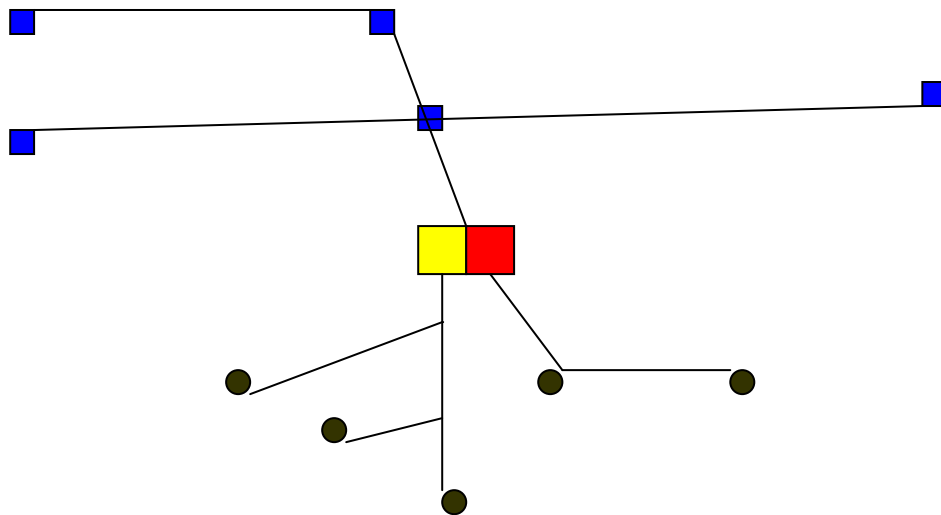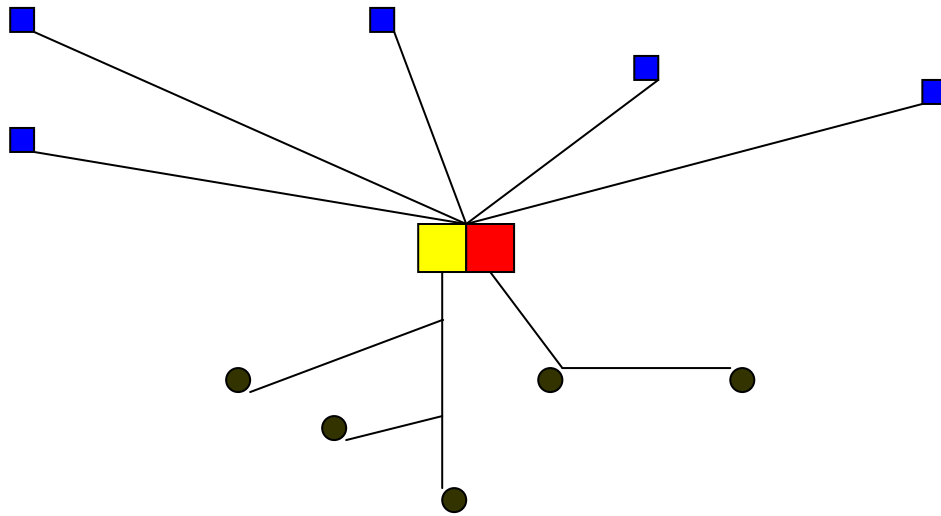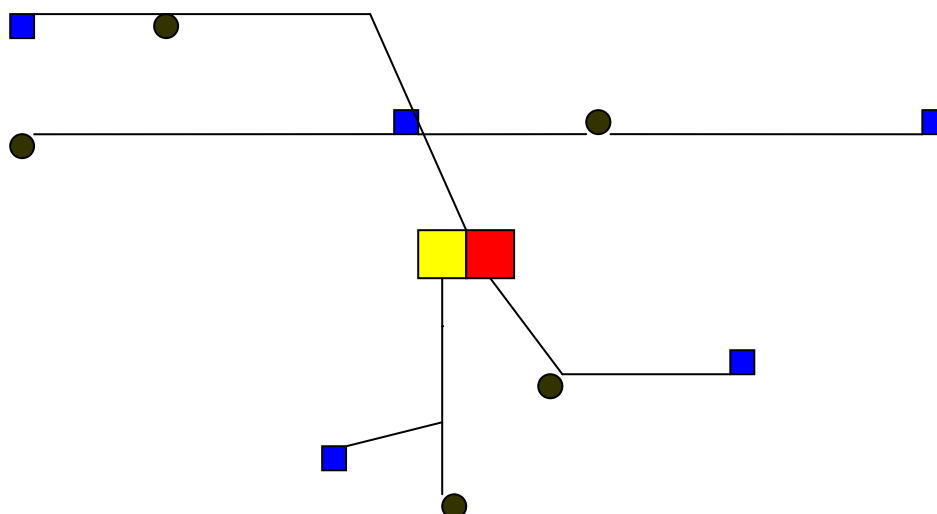
All players can see the 'map' with locations, the road network and distances (e.g. on a flip-over). The suppliers do not know how many items each supplier needs to deliver at each supermarket (this is varied from market period to market period). They only know their own required deliveries to the two supermarkets. The supermarkets know about all deliveries that they will receive in the market period and their deliveries to the outlets, but they do not know about deliveries of the other supermarket. Every player can be a buyer or a seller, and should in all cases make clear whether they are buying or selling. Buyers should quote bids and sellers should quote offers. All bids must be higher than the highest outstanding bid, should one exist, and asking prices must be lower than the lowest outstanding offer, should one exist. A buyer raises his/her hand and says for instance: "supplier B1 bids £18 for transporting one unit from B1 to A1". This bid can be accepted by someone, countered by an offer or be followed by another bid (for the same or another transport). A seller raises his/her hand and says for instance: "Supplier B2 asks £22 for transporting one unit from B1 to A1". All bids and offers can pertain to one unit to be transported, but also to two, three, etc. units as a package.

Yet another variant of this logistics experiment would use the same settings as in the figure above, but would have a staged experiment, to better express the situation where the supermarket is in the dominant position to 'call the tune'. So it could offer suppliers a choice of two sets of terms of trade (first stage):

a) to deliver to the regional distribution centre at a delivered price;
b) to allow the supermarket to collect from the factory at a factory gate price, which will be below the delivered price.

The suppliers (manufacturers) would be able to accept either or both sets of these terms (second stage). The supermarket would then choose how it wanted to do business (third stage). The supermarket would have information on transport costs and how it would be able to combine loads from different suppliers, and/or how it could combine supplier collection with empty running back from the shops, and the cost impacts of such arrangements. The suppliers would not know these things. They would have information on transport costs and the impacts of being able to combine

deliveries to different supermarkets. The supermarkets would not know this information.

7.3 Data collection and analysis

For each of the above transport and logistics experiments one needs about ten participants (it is recommended to vary the number of participants, starting with just a few and ending with about ten). Getting so many real shippers and carriers to participate in the above experiments is probably not possible, except at very high costs. However, all these experiments can be done with students playing the agents. The initial transport experiment with given costs is simple and can be carried out without computers. It might also be possible to do some of the logistics experiments using paper forms and a blackboard. The transport experiment involving batching and routing is so complicated that it probably can only be done on a computer, with a PC for every player. For all experiments, the students need to receive financial rewards (based on their performance: salience), that on average exceed their opportunity costs for the time involved.

The outcomes of the above experiments can be analysed by estimating regression equations explaining output variables from the experiments (e.g. profits, vehicle miles travelled), from attributes varied in the experiments (such as type of institution, type of information provided, number of competitors, number of zones, number of shipments to be carried). Panel data methods can be used to handle repeated observations on the same agents and tests for within-person correlation over time can be carried out (including whether there is an element of learning over time).

All these experiments do not in the first place aim at getting data that can be used to estimate a national or regional freight transport model. The main purpose is to compare different institutions, types of information exchanges, spatial configurations and distributions of power: what is their impact on prices and vehicle efficiency? This can produce insights on the interaction between various players that can be taken onboard in subsequent modelling work.

8. CONCLUSIONS

Experimental economics (EE) can be used in transport analysis to obtain data that are hard to get by other means and to study interactions between agents. Both of these aims are especially relevant for freight transport and logistics, where firm-specific data are often missing because of their commercial nature and where decisions on the same shipments involve several actors. On the other hand, the respondents in EE usually are not the actual decison-makers on some choice (as would be the shippers and carrier firms), the experiments need to be relatively simple (because non-experienced subjects should be induced to follow the rules of the game) and EE does not aim at mimicking real market situations. Therefore, EE should not be regarded as a natural candidate to deliver data for estimating (parts of) a national, regional or urban transport planning model. Interactive agency choice experiments and minimum information group inference, combined with (possibly more aggregate) revealed preference information, appear more promising in this respect.

Nevertheless, we think that EE can be applied quite fruitfully in transport and logistics research to test hypotheses (e.g. on shipper-carrier cooperation) and perform analysis on efficiency (both market efficiency and vehicle efficiency) and on information exchange in e-commerce.

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Annex 1. Protocols used in shipper-carrier model of Holguin-Veras et al. (2009).

Leading shipper experiment:

1. The shipper has a production cost function for a good that needs to be transported to a single receiver.
2. The shipper decides on shipment size/delivery frequency; different values lead to different transportation and inventory costs (programmed in a spreadsheet that the shipper can use).
3. The shipper announces shipment size/delivery frequency to all carriers.
4. Each carrier has three modes: van, truck, and combined road/rail. The modes have the same cost structure across carriers.
5. The carriers decide on the optimal mode for the job, compute their costs (using a different spreadsheet), decide on the profit margin, and submit bids to the shipper on a form sheet.
6. The shipper—price taker—selects the lowest bid, then records on the form sheets whether the bid has won or lost and returns the sheets to the carriers.
7. Then starts the next round. The bidding process is repeated until the shipper is convinced to have found the optimal shipment size/delivery frequency.

The leading carrier experiment:

1. The shipper only provides information to the carriers on the total amount to be transported.
2. The carriers each select a combination of shipment size, delivery frequency, and profit margin to maximise profits.
3. Each carrier can only use a single mode.
4. Then the shipper selects the carrier.