Coordinating Inventive and Innovative Decisions Through Markets with Prices: An Experimental Study of Patent Markets with Transparent Prices

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COORDINATING INVENTIVE AND INNOVATIVE DECISIONS THROUGH MARKETS WITH PRICES:
AN EXPERIMENTAL STUDY OF PATENT MARKETS WITH TRANSPARENT PRICES

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Abstract

The patent system makes organized markets in patents with transparent prices possible. Such prices are here investigated as “signals” for inventors and innovators alike of valuable “technology areas”, in an experimental study. They inform decisions of specialized “firms” on allocation of resources for invention given a search space of induced technology values. The traditional *hierarchical* model of coordinating invention and innovation in a vertically integrated firm is replaced by coordination of these activities among specialized firms through a *market* with prices. The experimental study builds on a study focusing on price mechanisms with exogenous technology values to a study of an economic environment with “endogenous” technology values. The results suggest that coordination clearly takes place but differs considerably between the institutions and patent validity tested (a 3 x 2 design). As with the price study, demand-side bidding in both dimensions of the linear contract appears to yield the broadest search scope, and thus the best chances for the allocation of resources for invention. Multiple end-states are observed, especially for institutions with less demand-side bidding, indicating imprecise price signals for institutions similar to today’s personal exchange. Coordination with prices appears to increase the dynamic gains of the patent system through price information to reduce or better inform about the risk in investments in new technology.

1. Introduction[1]

In this article, I wish to examine the coordination of inventive and innovative activities through markets with transparent prices. In particular, the willingness to (endogenously) search for new technology within a given search space of (exogenously) induced values is evaluated under different institutions and patent validities in an experimental economic study.

The standard example of such coordination typically does not take place through a negotiation process with transparent prices. This analysis goes beyond the gains from trade due to comparative advantage (Heckscher, 1919, Ohlin, 1924), static economies of scale

[1] I am grateful to the Saving’s Banks Research Foundation (Sparbankernas Forskningsstiftelse), Dir. Rodrigues and Royal Institute of Technology, Björn Hårsman for research support which have helped to shape the research agenda. See thesis: ULLBERG, E. (2009) From Personal to Impersonal Exchange in Ideas - Experimental Study of Trade in Organized Markets for Patents. *KTH TRITA-TEC-PHD 09-006***,** 180. In particular I also would like to thank Vernon Smith, Stephen Rassenti, and David Porter as ICES-GMU for their invaluable input on economic system design and economic experiments.

(Krugman, 1980) and the Schumpeterian world (1942) (1934) in which integrated markets increase the incentives for and the benefits from innovation (a market *size* argument). Such analysis takes a three phase approach: innovation, rewards, and technology becoming public. The analysis leads to an economy with a permanently higher growth rate (Krugman, 1990). The traditional approach follows a "temporary monopoly" discussion on the innovations (products) and invention and innovation are integrated in the same hierarchy.

In this model invention and innovation are not integrated in the same hierarchy but through specialized agents coordinating their activities through this market with prices. This article expands on previous articles on trade in organized markets for patents with prices and dynamic gains. In the first article an informal theory of prices for linear contracts on patents was outlined and a dynamic economic system was designed to be useful for experimental investigations (Ullberg, 2010c). In a second article, prices and gains from trade were investigated and the theory was tested for three demand-side bidding institutions under two levels of patent validity using a laboratory experiment (Ullberg, 2010b). Dynamic gains from trade were also studied as the propensity to "split" contracts on patents in two technical fields of use, pricing, and increasing the use of an *exogenous* technology with uncertain values.

In this article I wish to expand the study by introducing *endogenous* technology search for technology of different values in the dynamic microeconomic system where only the boundaries of search of technology are defined. Such search limits can be said to represent the technological research capabilities of a typical firm. The design uses Smith's (1982) microeconomic static system description[2] with extensions to include a dynamic system with a secondary market and a legal patent environment in a three period game with multiple system states as in the previous studies.

The key point of interest is the *search pattern*s that can be observed using the different institutions and patent validity. The attempt is to build a "bridge to reality"[3] when impersonal exchange in patents takes place in organized markets, by staying true to the principles of the patent system of *market exchange and social exchange*.

It is my contention that the price signals and trade in the patent rights based on publicly disclosed technology area information and demand-side bidding market institutions are important aspects inherent to the value of the patent system in the analysis of the social exchange that takes place for development of economically useful technology, specialization, and growth (through a complex coordination of publicly disclosed of technology through the patent system and public prices through a market exchange).

I will first give a background in terms of the model used (the trading system in section 2) and then a discussion of two search processed studied – one with a simple and one more complex "endogenous" search space (section 3). The details of the economic environment, institutions and software used are then presented (section 4) followed by an overview of the experimental design and results (section 5). Empirical results and initial hypotheses on coordination and willingness to search are tested in a comparative study between the institutions and patent validity in the 3 x 2 design (section 6). Finally, conclusions are briefly discussed and a proposition to address perceived deficiencies of the market economic system of capital investments in new products (innovations) is addressed (section 7). Some of the

[2] The system description ***S=(e,I)*** is expanded to specify technology as a knowledge discovery activity (inventing patentable subject matter) part of the economic environment (***e***) and a legal environment (the patent system) as part of institution (***I***). "… if learning is to be part of the economic process, then one must specify agent preferences and technology in terms of learning (or sampling or discovery) activities. In this case, the fixed environment would specify the limitations and serach opportunities for altering tastes and knowledge in an economy with changeable tastes and resources."

[3] The challenge that remains. Ref to : KRUGMAN, P. (1990) Endogenous innovation, international trade and growth.

policy implications presented in section 7 and in the thesis are elaborated on–in summary form–in (Ullberg, 2010a).

2. The trading system

Intellectual property has always, it seems, been at the center of economic activity. It has been kept private through many different means, such as trade secrets, but through the patent system technical knowledge has become *impersonally* tradable (see (Ullberg, 2010c) for a more detailed discussion on the economic history of the patent system). The technical knowledge remains private through the patent claims, but the information about what is invented becomes public through the patent disclosure. Today, the patent system has become "inseparable" from economic activity and is used in very sophisticated ways to protect market access. The rights allow the holder to exclude and/or transfer or license the rights, creating a *market* in ideas. Traditionally, this market can be characterized as a *personal* exchange market between individuals, firms and even nations without any organized way of pricing the patents (comparable to that of a stock market for shares). However, during the last two decades, the patent licensing market has dramatically grown in importance with increased specialization between actors inventing and innovating as a result. Also, specialized patent portfolio companies, "traders," have appeared. This was probably triggered by a "pro-patent" policy shift, particularly in the USA in 1982, when the benefit of the doubt was given to the inventor, the agent taking the risks. This has had the effect that patent validity—the chance that patents challenged in courts are upheld—has increased (in the US) from 38% in 1982 to 93% around 1999. The patent has become an asset comparable to a physical asset— presumed highly valid and therefore tradable[4].

However, this exchange rarely results in prices that are public, strongly "covering" any public *price signals* to inventors, traders and innovators about the value of certain technology areas. Some specialist firms do collect information on patent licenses and there are general "rules of thumb" for his information, shedding some light on the willingness to pay. However, to date no organized market with prices exists, although many efforts are currently being made in this direction[5]. A reason for this inability to trade impersonally was suggested in the results of the previous experiment (Ullberg, 2010b). Both buyers and sellers are uncertain whether public prices would be to their advantage. The experiment shows that impersonal exchange can take place using a linear contract and two-dimensional demand-side bidding. In this study, I use the same design markets for *impersonal* exchange in patents with *public* prices as in the previous experiment, providing the basis for signaling of the value. Inventors are given a "search space" that represents discrete patentable technology areas. Each area has an induced uncertain value for the buyers. The principle implemented here is thus coordination of investments in technology areas through market price signals.

3. Isolation of the problem

The first objective of these experiments was to determine whether agents would be able to *search* and identify the highest value technology when agents were faced with prices determined in competitive demand-side bidding markets by other agents. The previously cited experiment focused solely on prices of the contract and dynamic trade gains based on multiple uses, given uncertain values for *one* (exogenous) technology. To search among different

[4] It is illegal to license a patent that one suspects to be invalid, putting an often conciderable cost of "pre-license validation" on the sellers when presumed validity is low.

[5] There are initiatives of auctions such as bancruptcy auctions, government initiatives (Japan) and private organizations (US), but not yet an organized market with prices.

technology areas for a *better* area, given by higher value for the users, adds uncertainty to the knowledge development process and demands a certain level of risk-*taking* (entrepreneurial activity) in the breadth of searching.

The search results are not *private* information when using patents, but disclosed in the disclosures section and published by the patent system, thus making the *information* on the appropriated technology *public*. Making your intention (technical area) *public* is the price you pay to the society, i.e., other inventors, users, etc., in exchange for a grant of a time-limited *private* right to exclude others from trading that information. The disclosures are in a sense a "patent product" description. It is this information that is added to the experimental design in this second experiment. The search also demands prices that truly reveal any *differences* in values between technology areas. Consequently, it is an open question to what extent this additional entrepreneurial risk-taking will take place to search the "technology space," a *necessary* condition for coordination through prices.

All technologies have some value; thus, there is the behavioral preference expressed in the prospect theory of "loss aversion," which should limit search for new technology on the margin. There is some "gambling" involved in trying to find a better technology value and an "insurance" in continuing to use the same technology area. The risk-taking behavior may thus be affected by incentives given by the different institutional arrangements to price a new value (convergence rate, ability to differentiate between blocking and investment value, etc.).

The proper integration of information and rules in the institutions tested are therefore critical to integrate privately held information on the value of a given technology. Only through a process giving incentives to broad search can common expectations form that result in efficient outcomes. The level of "willingness to search" (WTS) will thus be a determinant of gains from trade through coordination of public information on the location of the technology area, with public prices and private rights.

If agents are not observed to search exhaustively, this supports risk-averse behavior induced by the impersonal *market* institutions and the *social* exchange of information (everyone is informed of the price (value) of an area whether the "inventor" benefitted (high value) or not (low value) from the effort). Also common initial expectations developed during the experiments (trained subjects are used) may be a limitation to search (the likelihood of finding a "higher" value than the highest found can be estimated). It is thus the principle of disclosure that is implemented in the dynamic model to make price signaling of fruitful technology areas possible.

The second objective was to investigate any differences in *gains* from trade through price coordination between the design market institutions and patent validity used. The incentives given by the rules and validity of patents influence prices and therefore may influence coordination efforts and convergence. Entrepreneurial activities carried out in the same hierarchy tend to create new knowledge on the margin, to reduce risk-taking[6]. A comparison between the institution similar to today's *personal* exchange and the others with richer language for demand-side bidding would reveal differences in gains from trade coming from an *impersonal* exchange. This question thus addresses whether there is a change in systemic risk-taking between the different means of economically organizing inventive activities to a hierarchy or specialized agents who coordinate through a market with prices. Will subjects interacting through a market with prices socially behave with more risk-taking, i.e., will the risks be shared in a more effective way? This is a systemic change that contains the *social exchange* aspect of the patent system[7].

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[6] This has also been the development of the patent system, from rather high demands to get a patent to gradually lower demands for patentability, making basic work efforts patentable.

[7] This question has a paralel in key management questions (hierarchy) where the information-sharing inside the organization typically results in a better outcome for the group.

To create an environment with uncertain values that could be explored during a single session, initially nine technology areas were offered but only three had any profitable values. This turned out to be too simple a search problem and nine random values gradually spanning from preference for investing to preference in blocking were chosen. The second "search space" turned out to be much more challenging, revealing preferences for investing and blocking for different institutions as well as multiple convergence end-states.

4. The economic system: Details of the institutional, economic and legal environment

The trading procedure employed in this study is a modified version of a specially built computerized trading system[8] for linear contracts. The software incorporates *endogenous* choice of technology area, the three institutional mechanisms tested (the primary markets), individual screens for the Inventor (Role1), the Trader (Role2) and the two types of Innovator roles (Role3A and Role3B), as well as a fixed price double-auction mechanism (the secondary market) used to re-trade the already negotiated contracts in period 1, in periods 2 and 3. There are three periods in each round. The trading mechanisms and patent validities are identical to those of the experiment for prices and gains from trade with *exogenous* technology values. The participant's screen displays were different for the different roles. An instruction set used during the experiment allowed participants to learn the interface more quickly by providing each participant with a detailed explanation of the different areas, boxes and information on their screen and what each role could do.

The flow of the experiment

Figure 1 gives an overview of the state diagram of the endogenous experimental flow in the experiment.

The experimental flow has three general phases which are repeated in each round: Inventing (1), Trading (2) (3), and Using (6) (4) (5). Inventing, primary market Trading, and Using take place in period 1, and secondary market Trading (5) and Using take place in period 2 and 3. The actual flow through the states is executed by the decisions of the participants. The Inventor is first asked to select a "technology focus" which is represented by nine "radio buttons" on a "technology map," representing the technical field of the inventor (1). Each selection has a *different*, initially unknown, set of induced (private) values. The Inventor is then asked to create a linear contract of "standard" or "quality" (1). The *private* values in a round are given for the three periods when the contract has been issued by the Inventor. The *private* values for the Trader and Users, and the *public* information on the technology focus and contract quality are given when the Inventor starts the auction by "listing" the contract with a first ask.

The contract is predefined as a license on an invention with "technology focus" "AB," useful for producing products of type "A" and "B". A quality contract can be split into one contract with focus "A" only and another contract with focus "B" only. The Trader is the agent who can split the AB contract into the A and B contracts; a quality contract thus allows the Trader to participate in the bidding process (2). If the inventor decides to invest in a standard contract, which cannot be split, the Trader is left out of the bidding (2) for that round. If the Trader wins the AB contract, and then subsequently splits it, the A and B contracts are sold in sequence to the Users of Role3A and Role3B respectively, with the Trader now being the seller and the Users the buyers (3). A User of type A can only produce products of type A

[8] The software is a modified version of the software used for experiment 1 on prices and dynamic gains from trade through multiple use of patents.

(their "product mix"), and vice versa for type B Users. If a standard contract is sold, all Users can participate, but there will be only one winner and one participant (A or B type) who can use the contract. If the contract is split, there are two participants (A and B type Users) who can use the two contracts and the Trader who used the AB type to split. As each bid/ask is entered, that information is *publicly* provided to all agents. The contract price (fixed plus royalty) is then a *price signal* for the value of the technology area and the contract quality to the Trader and Users (ultimately the consumers of the products A/B).

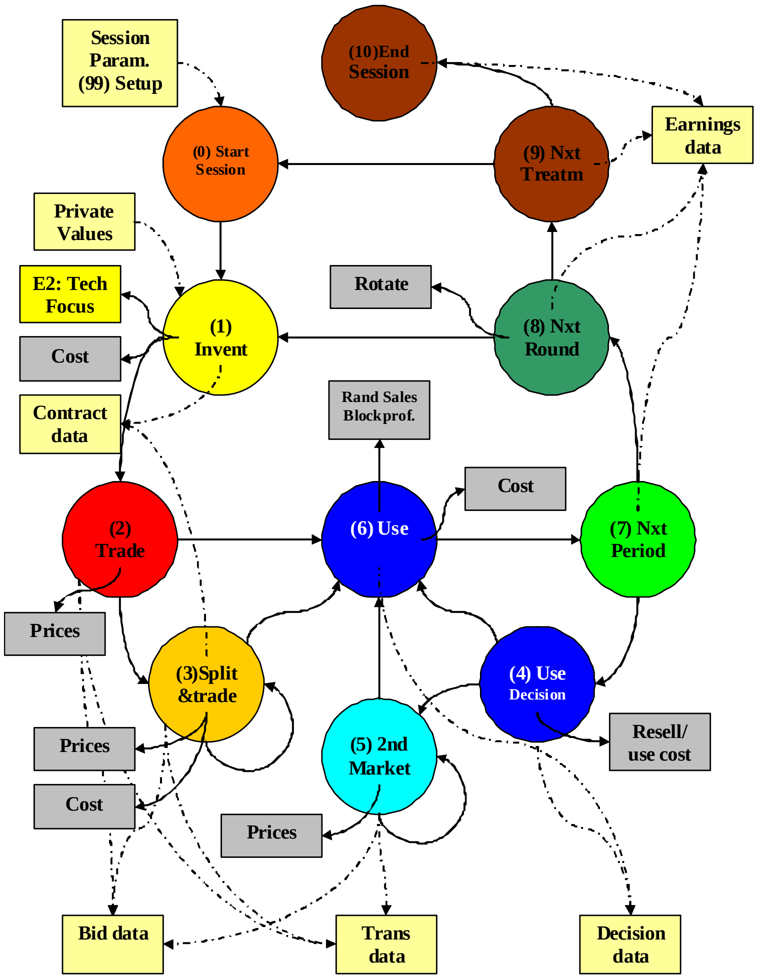

Figure 1. – State diagram of the endogenous experimental flow in the experiment.

The (binding) contract(s) sold thus eventually end(s) up in the "portfolio" of one User (with product mix A or B), or two Users (one with product mix A and one with product mix B) and a Trader (who holds the AB contract issued by the inventor). The User(s) holding the contract(s) are now asked (6) to either "Invest," which produces a profit based on increase in sales of the new more competitive product(s) A and/or B invested in, or to "Block" which produces a profit based on the existing sales of the product(s) based on existing technology the firm has been endowed with, "insuring" the firm's market access against competition based on technology. The sales and blocking profits are randomly drawn from a uniform distribution[9] in their respective induced value range displayed to the participant, after which period earnings are calculated for period 1 and the experiment moves to the next period (7).

[9] Other distributions were discussed in the ref. design article (a Poisson distribution).

At the beginning of period 2 and 3, the possibility to decide to resell the contract (or keep the contract) is given the holder (4) who starts the secondary market (5); then, if the contract is resold, the new holder is asked to use it (6) (cannot resell until next period). If the holder decides to keep the contract, then the holder is asked how to use it this period (6), after which the sales/blocking profits are randomly drawn anew within the respective value range and period earnings are calculated for all participants who held (bought/resold) or issued (in period 1) a contract, ending period 2. Period 3 proceeds in the same manner as period 2. At the end of period 3, total earnings are calculated for the round and the next round is started (8. In this round, roles may be rotated among participants with some frequency (for example every 2 or 3 rounds).

The trading screens

The participant's screens are rather complex "trading screens," but they follow the same theme and logic as described. The screens sections cover private, public and earnings/status information, useful for participants in making decisions. The private values and public information on the contract are given at the beginning of each new round. The values are given in ranges for the three periods. Thus, there are 6 ranges (3 for sales increase if contract is invested in and 3 for blocking profit if contract is used to block). Once role 1 has decided the technology focus and quality of the contract, role 3 and role 2 (if a quality contract) will have their private values displayed. The *public* validity and quality, as well as the the *private* discount rate for the contract, are also displayed with the values.

In the first mechanism, a two-dimensional version of a double auction (DA1), participants enter a price to buy (or sell) the contract by entering their fixed <u>and</u> royalty bid (offer) and then clicking on the button labeled "Send Bid" (or "Send Offer"). Participants can also accept any other participant's bid to buy (or offer to sell) by clicking on the button labeled "Accept Bid" (or "Accept Offer"). The acceptor must then confirm the acceptance by clicking "YES" (or "NO" to cancel the bid) on a pop-up box, which results in a *binding* contract to be formed; the exchange information is recorded in the public market information section on the interface. The auction is started by the seller (Inventor/Trader) with the first ask[10]. All past transactions are also listed with the last transaction first as a memory for the participants regarding negotiated prices for the different markets (primary market AB, A, B, technology focus, resell price, validity, and quality). The participants are given calculation tools to automatically calculate expected profits for rational expectations (mid-point value in range) and whether investing or blocking is decided.

Price quotes must reduce the bid-ask spread in one or both dimensions to be accepted. A buyer can ameliorate a bid, for example, by increasing the fixed bid without increasing the royalty bid. The five highest bids and lowest asks are displayed in a ranked order visible for all participants. Only the highest bid and the lowest ask are open for acceptance. Price quotes that violate this rule are rejected. Identical bids are thus rejected. The auction is started by the seller (a role1 or role 2) and ends when the bid and ask meet in both dimensions, when an "accept" is made, or when the auction times out, resulting in a "no trade" for that contract. In the case of "no trade," the seller must bear any costs associated with the creation of the contract (role1) or loss of fixed and royalty fees to cover cost against obligations from contract bought (role2). Buyers are not affected by a "no sale." The time-out function has two timers to speed up the bidding process: one for the maximum total time for the auction (usually 120s) and one for the maximum time between bids (usually 20s).

[10] This is different from a typical one-dimensional double-auction where the auction is started when the contract is listed. The buyer or seller can send in the first bid/ask.

The second mechanism, a double-auction with reservation value on the fixed fee (DA2), is identical to DA1, except when it comes to the amelioration rules. The seller can only *increase* the fixed component, i.e., the initial fixed quote is a *minimum*, not a maximum. The buyer can only *decrease* the fixed bid, i.e., their initial fixed quote is a *maximum*, not a minimum. This institution thus gives the seller the privilege of setting a binding minimum price on the fixed fee, which is a de facto reservation value. The royalty bid works the same way as in DA1.

In the third mechanism, repeated posted-offer, (PO), or a "manual" Dutch Clock auction, the seller enters a price quote in exactly the same way as in DA1. However, the buyers are limited in bidding space to a simple accept or reject of this offer by clicking on the button labeled "Accept Bid" or "Reject Bid." The information on who or how many have accepted or rejected the offer remains private. If all buyers reject the offer during a bidding round, then the seller can ameliorate the offer by reducing the quote in one or both bidding dimensions, just like in DA1, but here at a cost for each ameliorated offer. The bid-ask gap is unknown to both buyers and sellers until the quote is accepted by at least one buyer, at which time the binding contract is formed. The auction ends when the *first* buyer accepts the quote in the bidding round or there is a timeout. This mechanism could perhaps be called "manual Dutch Clock in two dimensions," where the "clock ticks" are provided by the seller's reduction in quote in every bidding round. Only the past offers are listed in a ranked order in the public market information.

The secondary market (5) is a standard fixed price double auction (FP-DA) common in asset experiments where the seller enters a fixed price quote for the contract in its portfolio, bought in a previous period. The contract terms (fixed, royalty) agreed upon in the primary market (2) or (3) are not re-negotiated and the contract is transferred "as is." Price quotes can be positive (seller gets money from the buyer) as well as negative (seller pays money to the buyer). This mechanism allows for already negotiated terms to be compensated for to a level acceptable to a buyer. The buyer (sellers) can also accept the highest standing ask (bid), as in DA-1. Contracts can be resold in periods 2 and 3. The auction is started as the seller decides to resell (4). The first quote can thus come from either the seller or a buyer. The quotes have to reduce the bid-ask spread. The auction ends when the quotes meet, an accept is made, or the auctioned is timed out. There is a timeout for the total auction time (90s) and for the maximum time between quotes (10s).

Trading occurs over a maximum of 30 rounds, each having three periods, lasting approximately 1-5 minutes each per round.

Subject payments, endowments and special "rules of the game"

At the beginning of the experiment, initial roles are assigned to the participants. There is one inventor (role1), two traders (role2), and 6-8 users (role3), with half in "industry A" capable of producing product A, and half in "industry B" capable of producing product B (if an odd number of users is involved there is one less in industry B). Each participant is endowed with a capital of experimental money at the beginning of a treatment. The purpose of the capital is to introduce "bankruptcy laws" and "loss aversion." The participants' earnings are decided by accumulated gains (losses) via contract issuing, splitting and using contracts held in portfolio during each period. At the end of the experiment, participants are paid a weighted sum of accumulated earnings in each role plus an hourly fixed fee (for keeping the capital positive) and a fixed show-up fee (for showing up on time), not counting the experimental money capital endowment. The exchange rate is decided at the end of the experiment (partly due to time constraints on the number of rounds in each session), and "converged" to 0.1 for role 1, 1 for role 2, and 0.5 for role 3, in order to make all roles approximately equally profitable (which turned out to be a difficult task for most agents).

If the accumulated losses deplete the capital, a one round grace period is given to the participant ("Chapter 11"); if the capital is still negative at the end of the next period, the participant is declared "bankrupt" and cannot participate further in that session. If this occurs, both the hourly fee and the show-up fees are lost (there is no payment for the session). This seemingly harsh measure was introduced to stop overbidding by many participants in the initial sessions. Participants are informed in the instructions about the linear nature of the contract, the decisions and activities each role can undertake, the uncertain nature of the sales and blocking profits generated by using the contracts, and the "bankruptcy rules." They can keep the instructions with explanations of the trading screens and experimental flow during the whole session. They are not informed about the distribution of values among participants (which is a linearly increasing function). At each session the technology map is randomly rearranged so that there is no prior expectation to the value locations. However, common expectations develop regarding "possible" values for the technology.

Invalidated contracts annul payment obligations (typical practice in real world). If a contract is invalidated, this information is immediately displayed in the market info box.

The number of participants varies between 9 and 11 in all sessions, changing the competitiveness of the demand-side between sessions. Each session is reported separately and all data can be related to an individual.

5. Overview of experimental design, design parameters, market performance, and the sequence of the experiment

I report findings from 14 experimental sessions using the design parameters listed in Table I. A 3 x 2 design was used for the study of coordination and dynamic gains from trade under three primary market institutions and two levels of presumed patent validity. 6 designs were run, exploring the coordination efforts in each combination of institutional and legal environment.

TABLE I

	Institutional and legal environment		Competition	Contract values			
Design	Institution	Validity (%)	Type A and B users	Contracts in session *	Values.Set	**Experiments**	**Data (rounds)**
1	DA-1	93	(4+3)	3 AB, 3 A, 3 B	Values9.1	1, 2.1	41
		93	(4+4)	3 AB, 3 A, 3 B	Values11.2	3.1	11
		93	(4+4)	9 AB, #5 low	Values13.1	3.2	20
		93	(4+3)	9 AB	Values14.2	4.1	30
		93	(3+3)	9 AB	Values15.3	7.1	30
2	DA-2	93	(4+4)	3 AB, 3 A, 3 B	Values10.2	2.2	22
		93	(4+4)	9 AB	Values14.3	5.1	18
		93	(4+4)	9 AB	Values15.2	8.1	31
3	PO	93	(3+3)	9 AB	Values14.4	6.1	22
		93	(3+3)	9 AB	Values15.4	8.2	30
4	DA-1	38	(4+3)	9 AB	Values16.1	9.1	26
5	DA-2	38	(4+3)	9 AB	Values16.2	9.2	30
6	PO	38	(4+3)	9 AB	Values16.3	10.2	37
							348

Cost structure:
Issue cost for Standard contr. 1 and Quality 2; Transaction cost = 1, COGS = 65%, Investment = 1, Patent renewal = 0
Cost of capital: 30% for Inventors, 5% for Traders, 10% for Users
*) The values are given in a range (a,b) to the subjects and a random value is drawn for the realization of the value using a uniform distribution. Different value sets were used to randomly change the value for the technology areas between sessions. From session 3.2, a low value was always given for #5 to avoid constant use of "center" position.

The initial sessions (1 to about 3.2) had simpler value sets and served as pilot/data sessions in their own rights. From session 4.1 more complex data sets with more relevant search space were used to better test the robustness of and differences between the institutions. The last session’s values spanned from preference to block to preference to invest, adding this aspect of the coordination problem to the test. The induced investing and blocking value ranges were positive, exploring the linear contract for positive prices as in the previous experiment. The values for the investment and blocking values were given in overlapping ranges, linearly increasing for the buyers to create a competitive bidding environment with only one “high value” bidder. The inventor was given a broad range spanning over the ranges of all the buyers, a typical condition for inventors. The traders were also given the full range, but spanning over each “industry’s” ranges. This was based on the presumption that traders typically have better information than inventors, being closer to the product market and having an “industry” view. The users had the most narrow (precise) ranges of values being in the market using the technology. A fixed cost of capital, specific to each role type, was used to discount the values over the three periods in each round. See Fig. 2 for an outline of the values used. The values show the midpoints of the range given to the highest value User.

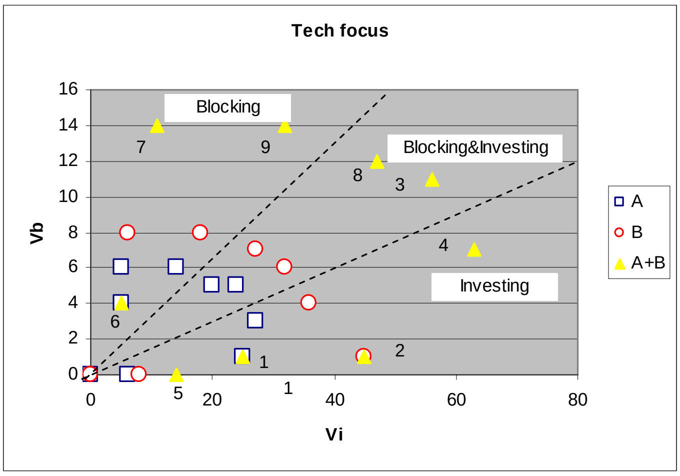

Figure 2. Induced values for Sessions 4.1 – 10.2 for technology areas 1-9. The technology values vary in preference to investing or blocking and NPV, with 4 the highest. For sessions 1.1 – 3.2 a simpler value set was used.

The first session was run both as a pilot, perfecting the design, and a data session. Subjects were recruited from the same pool that had experience from the previous experiment with prices and exogenous technology. This made training time minimal and the markets worked immediately in the new environment with the additional endogenous choice for technology. Data for technology focus were recorded in addition to the previously already-recorded quality decisions, bids, time series, prices, gains and other dynamic system parameters.

Experiments with high validity are reported first (design 1-3), by institution and market, followed by the experiments with low validity (design 4-6).

5.1 Coordination and gains from trade under high validity

5.1.1 Some initial observed coordination dynamics in the primary markets

The distribution of prices for the different technology areas 1-9 are visualized in Fig. 3-4 for the market mechanism DA1. In this “9 commodity market” in two dimensions with uncertain values, pricing patterns clearly suggests that the institution appears to generate distinguishable prices compared to predicted prices, although with volatility, especially in royalty.

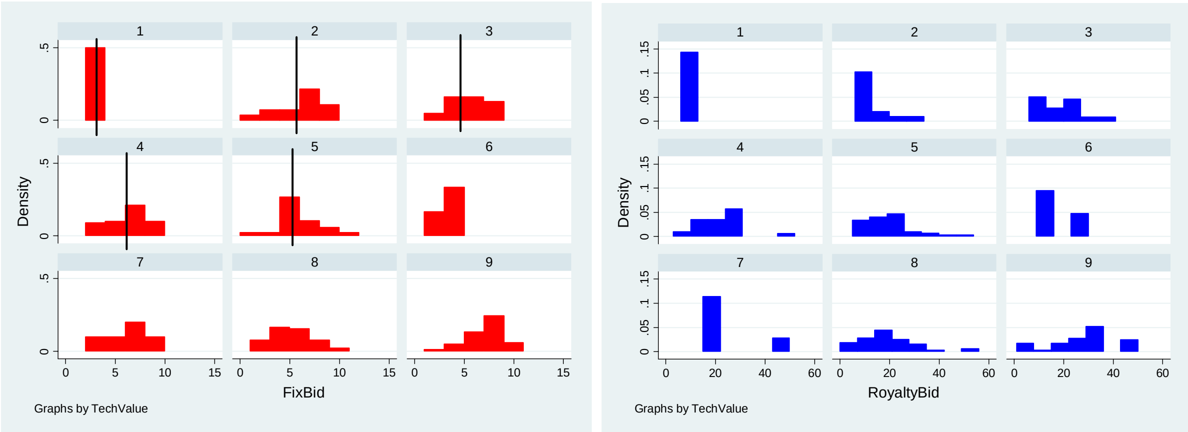

Figure 3-4. Prices for technology areas under DA1.
Average prices are indicated as solid lines and predictions as dashed lines.

5.1.2 Coordination by institution

The first experiments used a value set consisting of 3 AB, 3 A, and 3 B contracts, where the AB contracts could be split in one A and one B contract. The initial concern was that the price signals in this already complex "9 commodity" experimental market with linear contracts would not be clear enough for coordination decisions[11]. The values are called 1-9 in the figures and were assigned to the radio buttons with the AB contract on the diagonal, the A contract above and the B contracts below the diagonal. The values were randomly assigned in each category. The search pattern and convergence over time for experiment 1.1 is shown in Fig. 5.

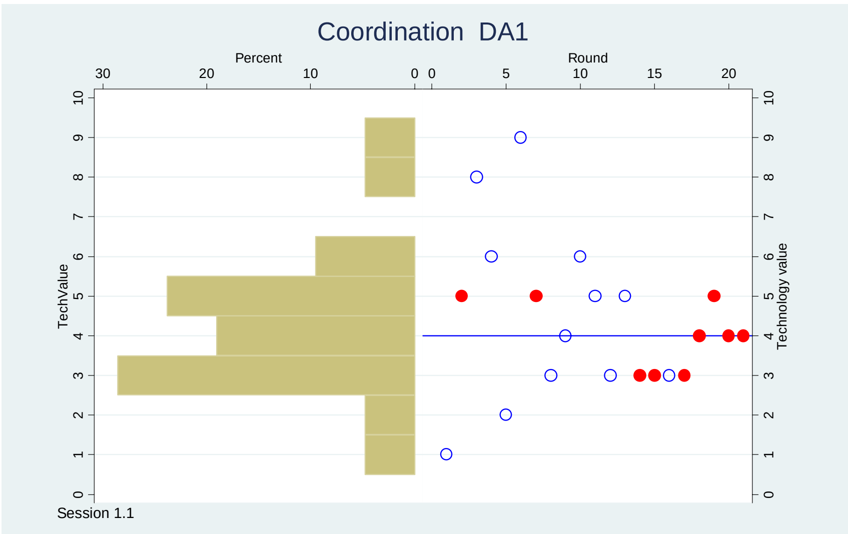

Figure 5. Convergence in Session 1 for DA1. The technology areas are shown on the y-axis with #4 having the highest net present value. Filled dots indicate quality and hollow standard contracts.

[11] In the experimental auction literature, often 3-4 rounds are needed to create common expectations and reach a theoretical price or stable trading pattern in a *one*-commodity market.

Subjects tried 8 of 9 technology areas, early discarding the lower valued A (#1,6,7) and B (#2,8,9) contracts, then tested out the 3 AB contracts (#3,4,5) and appeared to settle for area #4, which is the area with the highest NPV. In the process, 4-6 contracts were priced for *each* of the areas 3-5, giving *prices* a chance to converge (subjects had the transaction history on their screens). Average prices (fix, royalty) for #3 were (6, 22), for #4 (7.5, 25) and for #5 (6.6, 18.4); thus the average price signal indicated that #4 is the most valuable for the users, irrespective of its use (invest or block). Another way to look at convergence is by frequency. A high frequency would indicate the perceived usefulness for that tech area under rational expectations, a measure used in all of the experiments hereafter. The contract type issued was initially the cheaper standard contract and later a splitable quality contract, indicating that a narrowing search was first done at a lower cost before more valuable and costly contracts were invested in. In the following sessions, 2.1, 3.1 and 3.2, limited search was observe, suggesting common expectations had formed in the first session about the AB contracts being more profitable than the A and B contracts. Fig. 6 charts these sessions.

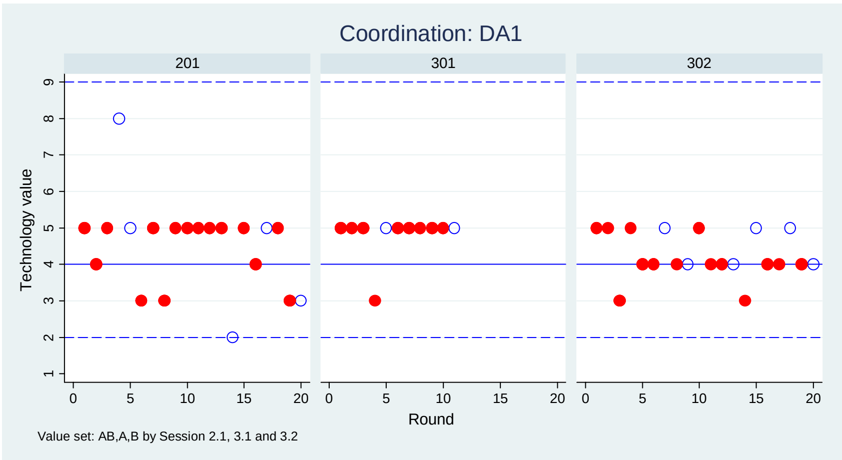

Figure 6. DA1: Session 2.1, 3.1, 3.2. In Session 3.2, the values for #5 were reduced, resulting in increased search among the three AB contracts (#3, #4 and #5).

What appeared to be a tendency to select the geometric center of the technology map (#5) was observed. To avoid what appeared to be a selection bias for the center of the map, or possibly too little variation in the AB contract values for price differentiation, a low value was given for area #5 in session 3.2 to increase the incentives for search. This resulted in a renewed search, still among the AB contracts, and #4 was discovered and received the most "hits." However, still #5 received many "hits."

These initial and convincing results of coordination through linear prices motivated a change in the value set to broaden the search space from 3 to 9 AB contracts, not using the A- and B-only contracts. The idea was to use a range of values spanning from predominantly investment values to "dual" invest/block values to predominantly blocking value. *Competing* price convergences would be possible (given individual tastes for risk-taking in the search). These value sets would then provide a difficult "robustness test" of the coordination for the different institutions, where preferences would interact with willingness to take risks (gamble) in the search. The following sessions were thus considerably more complex in nature, with only AB contracts resulting in more complex search and convergence patterns.

Comments from subjects suggested that once "OK" contract values had been found, they tended to stay with those, since "I might end up with a low value contract when it's my turn in role 1 (inventor)." To remedy this "high-risk low-return" problem, the roles were rotated first every 3 rounds, then every 2 rounds (to give "two chances"). When rotated every round the risk-averse behavior was clear. Risk-averse behavior appeared to be a common behavior. Only a few people responded differently by searching for a new area when others did not. When asked after the session why they searched so extensively, one person said "I always want to try some new thing. Perhaps there is a good value there." Another said "If I try something new, then the others will find out whether it is good or not, and then when it is my turn again, I will benefit also." These comments are consistent with risk-taking and *social* exchange through *impersonal* markets. In the patent system, a motivational *principle* is disclosure of what is invented so that others may benefit, not only after the patented technology has expired, but as an input for further research in a particular area. This principle appears to be at work in a social context with some of these subjects. *Searching* may thus be a social activity, not just an individual activity, given a patent system[12]. However, entrepreneurial people were "a rare flower"[13].

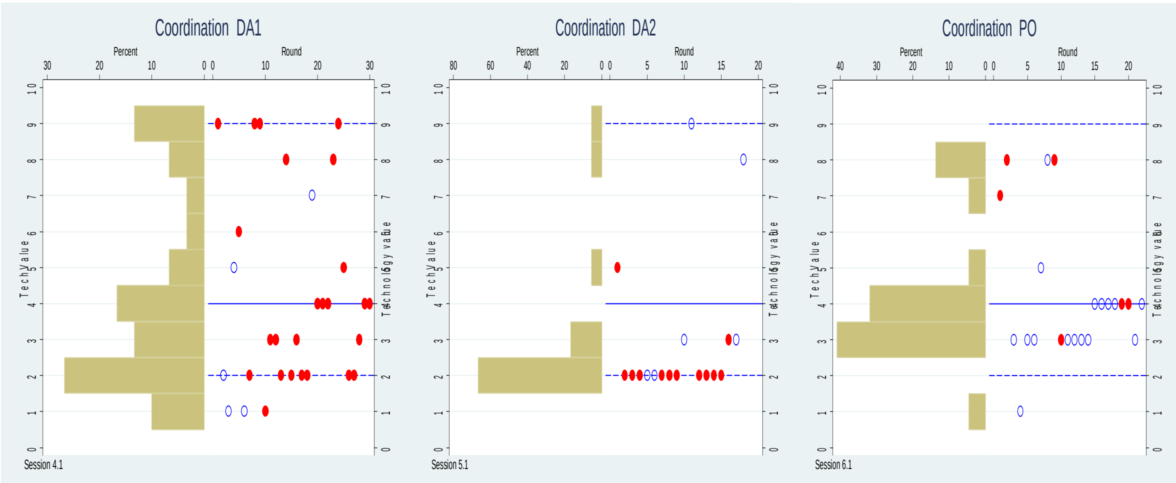

Figure 7. Session 4.1 (DA1) 5.1 (DA2) and 6.1 (PO). Dashed lines indicate highest investment (#2) and blocking (#9) value. Highest NPV is at #4. Circles are standard, filled circles quality and triangles split contracts.

In experiments 4.1, 5.1 and 6.1, charted in Fig. 7, the more complex value set was used across the three institutions. For tech areas #1-4 the investment values dominated and for #6-9 the blocking value dominated, with #5 having low values for both. A different search pattern appeared for the mechanisms, clearly distinguishing the institutions in propensity with respect to" 1) willingness to search, 2) convergence to any given technology area; and 3) dynamic gains from trade (measured as propensity to split). For the DA1 the whole tech area was searched at least once, low value contracts were quickly rejected, and high value contracts were revisited. These high value contracts were characterized by: focus on investing (#2), focus on blocking (#9) and, dual focus #4. The most used contract, including the dynamic gains from split. was #4 (highest NPV). The last two contracts were also #4. This indicates that DA1 appeared, in this session, to discover the three high value contracts as well as to

[12] Compare Arrow's definition of rationality: "Rationality and knowledge of rationality is a social and not only an individual phenomonon". ARROW, K. J. (1986) Rationality of Self and Others in an Economic System. *The Journal of Business,* 59**,** S385-S399.

[13] Discussing the problem of limited willingness to search with Prof. Vernon Smith he though that these particular subjects just might not be willing to jump in there, adding that "entrepreneurial activity is a rare flower".

"converge" to some extent on the highest NPV. We also see that contracts of some value are revisited 2-3 times before abandoned, presumably in order to get a clearer price signal (enough information to form common probability expectations). For DA2 and PO, there were less search and price discovery, even for valuable contracts. In the case of DA2, where a reservation value is set on the fixed by the seller, the contracts with high investment value appear to be most attractive (#2). Such contracts allow for trading off some royalty for a fixed. In the case of PO, a more clear focus appears. Coordination converges for the "dual value" contracts (#3,4), first for #3, and then to #4 (the highest value contract), but with *no* trade gains from split contracts. It is clear that the coordination even in this complex environment appears to converge to the higher values. What appears to differ between the institutions is the *type* of contract values (invest, block of both) the search processes converge to. Although this is "noisy," data the willingness to search appears to be related to the number of demand-side bidding dimensions.

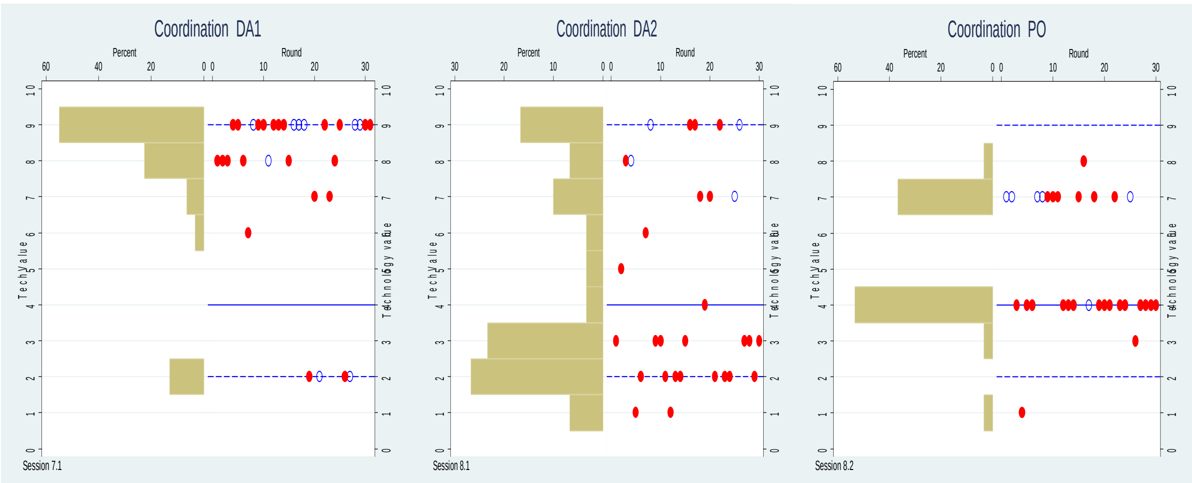

Figure 8. Values 15.1-3 Session 7.1, 8.1, 8.2; 5.1 and 8.1, DA2

The next set of experiments, 7.1, 8.1 and 8.2. (See Fig. 8) had the value set shown in Fig. 2. The values systematically covered the value space between investing and blocking with more pronounced blocking values than the previous experiments. A different search pattern appeared. DA1 converged to #9 and basically stayed put at the high blocking high investment value contracts. Interestingly, area #2 had about the same NPV for investing but almost no blocking value. The contracts were also used mostly to block. This may suggest a preference for blocking[14]. Again it is one of the high value contracts where the convergence is strong. In DA2, every technology area was searched with highest frequencies for high investment (#2), blocking (#9) and dual contract (#3). The highest value of #4 was tested but not discovered. The convergence appears to be on #3, which has the highest NPV of the three. For PO, the search pattern is similar to the previous ones, in that it clearly appears to be the most limited. The convergence appears to have two "equilibriums" with one at #7 (which has the highest blocking value, together with #9) and #4, the dual value contract with highest NPV.

[14] This is argued in the previous article to be consistent with prospect theory and "loss aversion."

5.2 Coordination and gains from trade under low validity

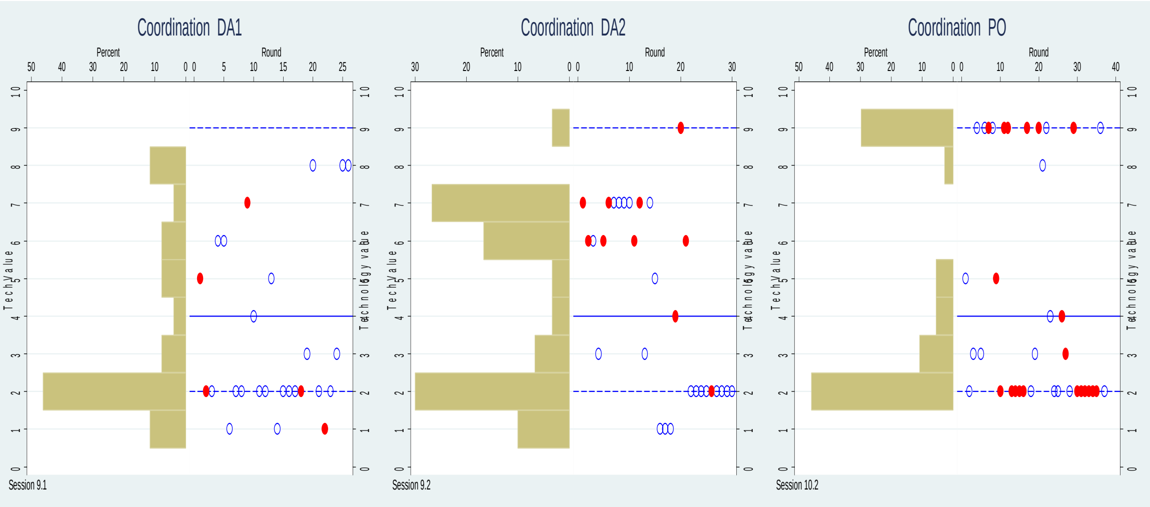

Figure 9. Low validity, Session 9.1(DA1), 9.2 (DA2) and 10.2 (PO).

A last set of experiments covering low validity are chartered in Fig 9. These experiments were run as the last sessions and thus with the most experienced subjects. Clearly a broader search is taking place. Also, there are few gains from trade coming from split contracts. The similarities between the institutions are also bigger. These two results were also observed in the previous experiments. All end up in coordinating at #2. DA1 basically keeps the focus on #2 whereas DA2 moves from #7 to #2 and PO has the "characteristic" dual convergence with #2 and #9, as for high validity. The speed of convergence is clearly DA1 > DA2 >> PO (with possibly two Nash equilibriums). The speed of convergence is of course critical to the efficiency in a technology search process. The general tendency with DA1 ~ DA2 > PO appears to remain.

A summary of all 6 treatments is shown in Fig 10. High validity leads to more searches and an indication of willingness to search appears to be: DA1 > DA2 > PO.

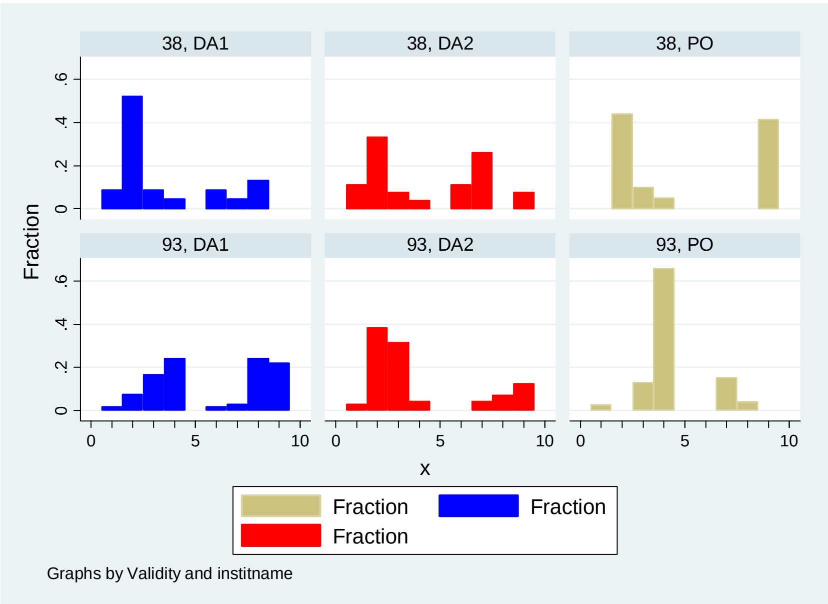

Figure 10. Summary of search patterns for different institutions and validity. Data from #5 are not shown.

5.3 Secondary market usage

The secondary market, used to reallocate contracts in period 2 and 3, was used only 3 times for DA1 and 1 time under a DA2 treatment. The conclusion here is that the initial allocations were mostly satisfactory and the study can be said to study any differences from primary market allocation on convergence.

5.4 Summary

I conclude that there are strong indications that coordination through markets in linear pricing of inventive, trading and innovative activities is supported in the dual value environment of a patent. There also appears to be a tendency toward multiple equilibriums, or end-states in the system, making technology area choices “swing” between a dominant investment, blocking value or a dual value. The reason for this appears to be the investment and blocking values of the contract on patents traded, and the strength of the price signal in the two dimensions, i.e., the institutional characteristics. 1-3 “trials” were made to accept/reject a technology area. The richer the demand-side bidding, the better the coordination appears to be. Comparing the institutions, the willingness to search appears to be broader for DA1 and DA2 than for PO. DA1 appears to better identify the values (ex. in 7.1 DA1 discovered #4 as a major value where as in 8.1 DA2 did not). A tentative ranking in search and convergence would then be DA1 >= DA2 > PO. The best convergence thus appears to be observed as a result of the richness in the demand-side bidding.

6. Coordination, hypotheses and empirical results

In formulating some hypotheses on coordination, I will distinguish between the ability to search and convergence and differences between institutions.

6.1 Does convergence take place?

Convergence is defined as a repeated selection of a technology area with a frequency greater than 4. With this criteria, there is clearly a convergence in every experiment for every institutional and validity treatment. However, in some cases, in particularly in PO, there are often two tech areas with convergence, one with a high investment value and one with a high blocking value.

6.2 Differences in willingness to search between institutions and validity

To compare search patterns between institutions, a Chi2 test is used to compare the frequency distributions of technology value searches. The hypothesis is that the institutional rules result in different incentives and different search patterns. See Table III.

Table III: Comparisons between institutions.

93% validity: Session 4.1, 5.1, 6.1, 7.1, 8.1, 8.2

TechValue	Instit PO	DA1	DA2	Total
1	2	3	2	7
2	0	13	28	41
3	10	8	23	41
4	52	11	1	64
5	0	1	1	2
6	0	2	0	2
7	12	5	3	20
8	3	19	5	27
9	0	41	9	50
Total	79	103	72	254
Pearson chi2 (Pair wise comparison)	0.000***	0.000***	0.000***	

38% validity: Session 9.1, 9.2, 10.2

TechValue	Instit PO	DA1	DA2	Total
1	0	2	3	5
2	18	12	9	39
3	4	2	2	8
4	2	1	1	4
5	0	3	0	3
6	0	2	3	5
7	0	1	7	8
8	0	3	0	3
9	17	0	2	19
Total	41	26	27	94
Pearson chi2 (Pair wise comparison)	0.000***	0.101	0.000***	

The conclusion to this is that the search patterns are significantly different for high validity and for low validity, except between DA1 and DA2 for low validity. The differences appear to be that DA1 discovers more precisely the highest valued technology area (4) and highest investment-only (2) and highest blocking-only areas (9). There are 1 - 3 end-states observed. The frequency “distribution” actually matches fairly well the value distribution of the technology areas. A possible explanation for this is that DA1 allows buyers to bid independently in fixed and royalty; thus, buyers and sellers are able to reach an agreement if one or both values are high (supports the informal price theory). DA2 appears to converge on highest investment-only area (2) and high dual values (3), but with less emphasis on blocking-only areas. A possible explanation here is that since sellers set a reservation value on fixed, a high investment value allows the sellers and buyers to trade off some over-pricing with respect to the blocking value by reducing the royalty. Such behavior would favor contracts with high investment values. This is not possible with blocking-only contracts. A reason why the highest value (4) was not discovered in the session may be that it was only tried 1-2 times and it appears that 3 times were needed to accept/reject a technology area (*price* conversion). PO has considerably less search span and appears to stay on initially found high values, often dual values (4, 7). A possible explanation for this is that since the sellers set the offer in two dimensions, buyers are more willing to accept when the values, which are unknown to the sellers, are also matching, i.e., also in two dimensions.

6.3 Coordination

Coordination appears to work as technology focus converges on contracts with among the highest blocking and investment values. The different search patterns observed for the institutions suggest, together with the convergence, that there may be multiple end states of convergence. These are typically on a high blocking value, high investment value or high blocking and investment value contracts. There is an indication that the coordination is more stable (a single sustained Nash equilibrium) with increased demand-side bidding (DA1 > DA2 > PO).

7. Conclusions

Coordination appears to work between invention, trade and innovation through a market with linear prices. In the space searched, all institutions converge on the highest values, often resulting in multiple end-states (Nash equilibriums). In terms of willingness to search broadly and coordinate to the highest technology value area, a tentative ranking can be done between the institutions where DA1 >= DA2 > PO. This suggests that *demand-side bidding* in one (DA2) or both dimensions (DA1) are important for gains to trade from coordination through market prices. Since PO is the institution most similar to today's personal exchange, the results indicate that gains from trade in organized markets with prices may come from better allocation of resources for *invention* in a market with prices using demand-side bidding. Search also appears to be motivated by personal and systemic exchange (social exchange motivated by the patent system disclosure principle) as well as impersonal exchange and profits (market institution) as subjects try new areas not only as a one-shot "gamble" but with learning effect for others that may benefit them later ("sowing" in one role and "reaping" in another role or in the same role), whether this behavior is reciprocated or not.

There is a clear unwillingness to continue to search once a "profitable enough" value has been found. This results appears to be consistent with prospect theory (Kahneman and Tversky, 1979). The differences between the institutions can then be interpreted as a risk premium with respect to search cost. This risk premium is on the price risk, since the difference between the institutions is entirely in the language of demand-side bidding (same contract and same two-dimensional ask from the seller).

I conclude that demand-side bidding in one dimension, and especially in two dimensions, reduces the price risk of the institution and is positively correlated to the willingness to search and thereby correlated to gains from trade with respect to allocation of resources for *invention.*

The model can therefore be seen as an extension of allocation of resources in a hierarchy (Arrow, 1962) to such allocation through a market. The model is also an example and extension of the provisions by Smith on his model of microeconomic system where changes in learning can be characterized as discovery activities with some search limits altering knowledge in an economy with changeable resources (Smith, 1982) p. 924.

These result also negates, in principle, Robinson's contention in "What are the questions?" (Robinson, 1977) p. 1337, that the problem in the capitalistic system for allocation of resources for innovation is the management of funds and new ideas in the *same* hierarchy, leading to under-development of new ideas. The exchange of the ideas themselves in competitive markets with prices may provide a solution to this problem, as reported in these experimental gains from trade.

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