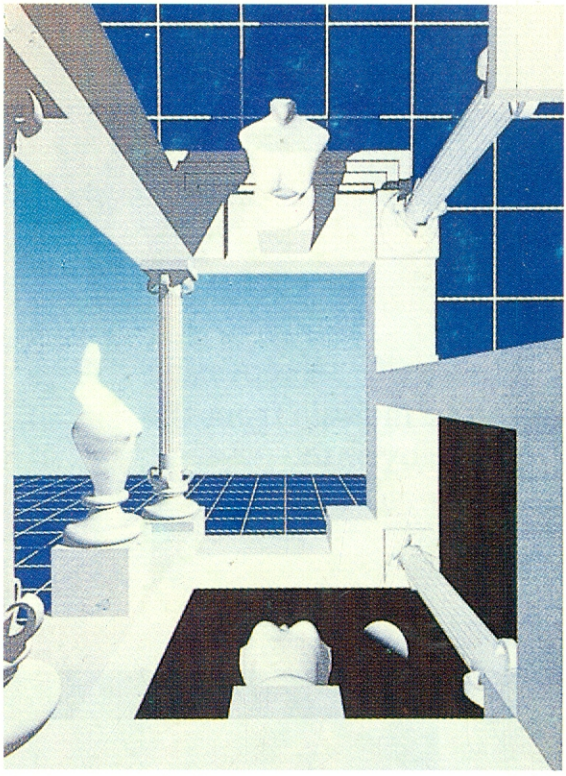
# LEONID HURWICZ
# DOCTOR HONORIS CAUSA





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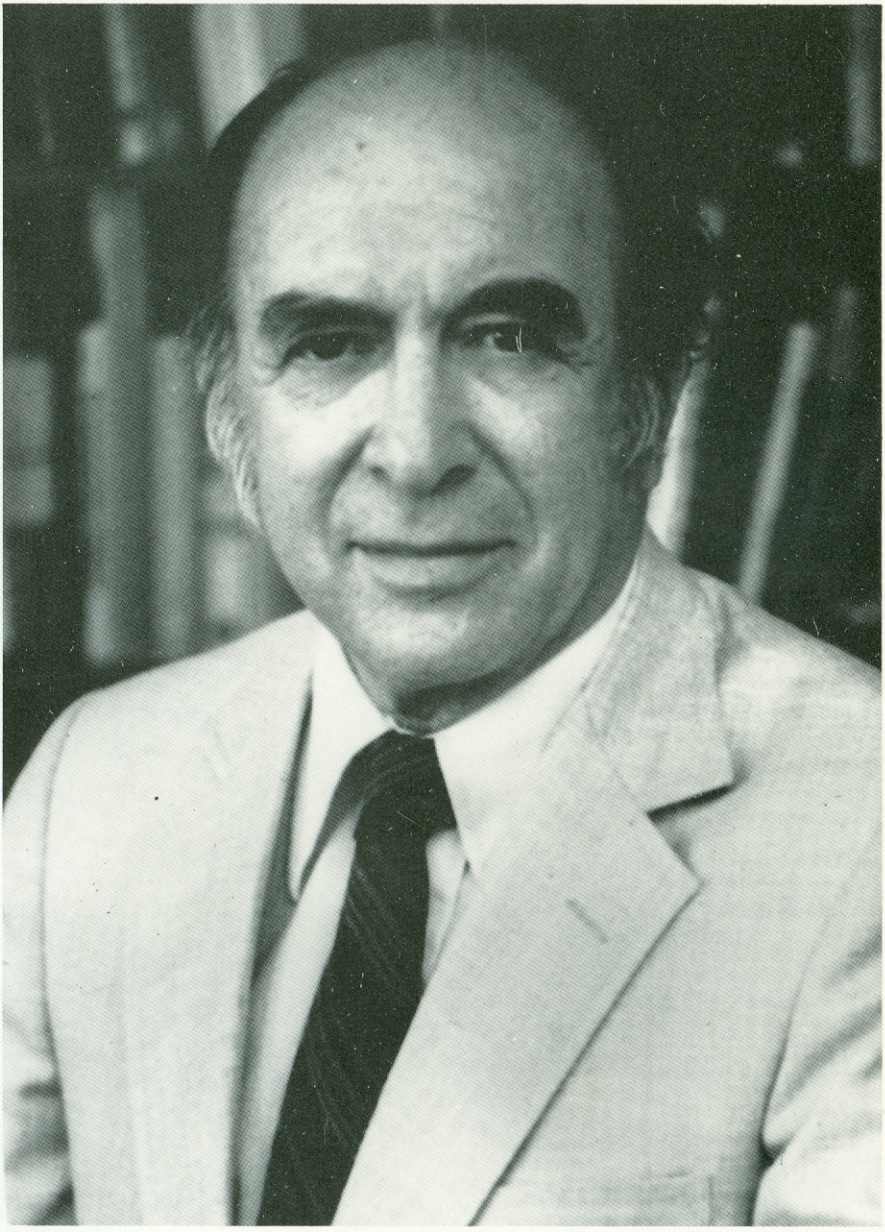

UNIVERSITAT AUTÒNOMA DE BARCELONA

# DOCTOR
# HONORIS CAUSA

## LEONID HURWICZ

DISCURS LLEGIT A LA CERIMÒNIA
D'INVESTIDURA CELEBRADA
A LA SALA D'ACTES D'AQUEST RECTORAT
EL DIA 14 DE JUNY DE L'ANY 1989



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# PRESENTACIÓ DE LEONID HURWICZ

PER

**XAVIER CALSAMIGLIA**

Excel.lentíssim i Magnífic Senyor Rector,
Digníssimes Autoritats,
Estimats Col.legues,
Senyores i Senyors:

En els seus vint anys d'història, aquesta és la primera vegada que la Universitat Autònoma de Barcelona concedeix el títol de Doctor Honoris Causa a un economista. És un honor per a mi presentar el professor Leonid Hurwicz com a mirall en què es reflecteixen totes aquelles virtuts i qualitats que voldríem que presidissin sempre les activitats d'una Facultat d'Econòmiques jove i emprenedora, que té com a objectius la formació d'economistes i el cultiu de la ciència.

Leonid Hurwicz neix a Moscou a l'estiu de 1917. La seva família es trasllada de seguida a Polònia, on creix i s'educa fins a obtenir el títol de llicenciat en dret per la Universitat de Varsòvia l'any 1938. Passa dos anys a la London School of Economics i a l'Institut des Hautes Études Internationales de Ginebra, fins que l'any 1940 emigra als Estats Units.

Arriba a la Universitat de Xicago poc després que la Cowles Comission for Economic Research es traslladés a aquesta ciutat des de Colorado Springs. Són els anys en què el feixisme genera un flux ininterromput de científics des d'Europa cap als Estats Units. No és difícil d'imaginar l'efecte que l'ambient de la Cowles Comission havia de tenir sobre el jove Hurwicz. La direcció de Jacob Marschak -home dinàmic, obert i amb un gran olfacte per detectar el talent- dóna a aquest centre de recerca un caire molt peculiar i una volada que possiblement no es podrà repetir mai més. Per donar-vos-en una idea citaré uns quants noms dels joves investigadors que allí es reuneixen: Arrow, Debreu, Haavelmo, Klein, Koopmans, Lange, Marschak, Modigliani, Patinkin, Reiter, i Simon. Dels trenta-tres investigadors incorporats a la Cowles Comission en aquella època, sis han obtingut ja el Premi Nobel d'Economia. Els grans canvis que

es produirien en la teoria econòmica als anys cinquanta i seixanta, amb l'esclat de l'econometria i l'economia matemàtica, es covaven ja als seus seminaris de treball.

Com ha dit Hildreth, la primera impressió que hom treia del seminaris de la Cowles Comission era que tothom parlava a l'hora i que hi havia fortes baralles per aconseguir un tros de pissarra. Afortunadament, els diversos i marcats accents de tots els participants i els guixos de colors diferents permetien que cadascú anés seguint l'argument preferit. Aquell ambient mogut, irrespectuosament creatiu i crític i al mateix temps disciplinat i rigorós, devia fer sentir Leo Hurwicz com a peix a l'aigua. Arrow descriu així el Hurwicz d'aquells anys: "Leo ja era, de sempre, fresser i ple d'idees, sovint massa ambicioses per ésser realitzades. Moltes, però, han estat formalitzades vint anys després. També era un crític molt agut". Klein comenta: "Hurwicz era en algun sentit el tàvec del grup: que jo sàpiga no tenia cap missió concreta i es ficava en els problemes dels altres amb fiblades agudes i penetrants".

L'any 1946 accepta una plaça de professor associat a l'Iowa State College i després d'una curta estada a la Universitat d'Illinois acaba per anar a raure a Minnesota, on ha estat professor fins a l'actualitat. S'ha mogut molt, això sí, perquè ha estat professor visitant, entre d'altres, a les universitats de Stanford, Bangalore (Índia), Harvard, Berkeley, Tokyo, Northwestern, a l'Institut Tecnològic de Califòrnia i a la Universitat Popular de Pequín (Xina Popular).

Fóra molt llarg de fer referència a totes les seves contribucions científiques, que han tingut un impacte decisiu a l'hora d'eixamplar les fronteres del coneixement econòmic. Parlaré, però, dels camps en què la seva aportació ha estat fonamental.

## Integrabilitat de les funcions de demanda

La teoria econòmica sempre ha explicat la conducta dels individus com a resultat d'una elecció racional entre alternatives. Per elecció racional s'entén tota aquella decisió que es fa d'acord amb un sistema de prioritats ben definit. Naturalment, aquesta elecció es fa entre les alternatives factibles, i el factible en un moment determinat depèn de certs paràmetres com ara els preus i els nivells de renda. La funció de demanda descriu el comportament de l'individu en expressar les quantitats de béns consumides en funció de preus i nivells de renda. En els llibres de text s'explica normalment com s'obté la funció de demanda a partir d'unes preferències donades i quines són les propietats que aquesta funció ha de tenir pel fet d'ésser la conseqüència d'una elecció racional.

Per a un economista professional, aquesta no és la qüestió més interessant. La funció de demanda és observable i es pot estimar a partir de dades empíriques sobre nivells de preus, de renda i de consum. Les preferències, les prioritats o la funció d'utilitat que les representen no són observables. Per esbrinar-les, es podria fer una enquesta. Però l'economista sap que la resposta depèn crucialment de l'ús que l'entrevistat sospiti que se'n farà. Per això, és més adient intentar d'inferir les prioritats, les preferències i les valoracions dels agents a partir de la seva conducta observable. La pregunta concreta és: sota quines condicions és possible de reconstruir les preferències a partir de la conducta observada?

Aquesta és una qüestió que ja va ésser estudiada per Antonelli, Pareto i Volterra al tombant de segle. Samuelson va tornar a tractar el tema l'any 1950. Hurwicz i Richter hi van fer contribucions decisives els anys setanta.

## Programació matemàtica

Tant els problemes de comportament individual com les possibles definicions d'eficiència i d'optimitat econòmica es plantegen com a problemes de maximització condicionada. No és estrany, doncs, que els economistes hagin mostrat molt d'interès per la programació lineal i els teoremes de dualitat que fan aparèixer els preus ombra com a valoracions implícites en tot problema de maximització. Hurwicz comença la seva llarga col.laboració amb Arrow treballant amb extensions del teorema de Kuhn-Tucker. També treballa en l'extensió d'aquests teoremes a espais lineals de dimensió arbitrària. Però poc després s'interessa, de nou juntament amb Arrow, pels aspectes dinàmics del problema, en particular per algoritmes que, com el mètode de gradient, permeten el càlcul de les solucions mitjançant un procés d'aproximacions succesives.

## Estabilitat de l'equilibri competitiu

L'equilibri competitiu és una situació en la qual les decisions independents de tots els agents econòmics enfrontats a uns preus donats són mútuament consistents i no hi ha, per tant, cap força que alteri el sistema. S'ha argumentat, però, que només els equilibris estables tenen interès, perquè són els únics que poden ésser observats. Com solia dir Hurwicz a classe, teòricament és possible col.locar un bastó de passeig, d'aquests que acaben en punta, perfectament vertical de manera que es mantingui en aquesta posició, però, algú ha vist mai un d'aquests bastons aguantar-se dret tot sol?

Arrow i Hurwicz partien dels treballs previs de Hicks i Samuelson. El treball de Hicks utilitzava les propietats de l'equilibri competitiu (com, per exemple, la llei de Walras), però el concepte d'estabilitat que emprava no era formulat en un context dinàmic, que és l'apropiat. Samuelson, per altra banda, va entendre l'estabilitat com un problema explícitament dinàmic, però no va explotar les

propietats específiques de l'equilibri competitiu. Arrow i Hurwicz van omplir el forat tot analitzant en un context dinàmic l'estabilitat del sistema (per contraposició a l'estabilitat d'un equilibri concret) i van introduir l'ús de les funcions de Lyapunov, cosa que els va permetre d'estudiar l'estabilitat global, és a dir, la resposta del sistema quan les pertorbacions no són necessàriament petites.

## Mecanismes descentralitzats d'assignació de recursos: informació i computació

Aquesta és probablement una d'aquelles "idees massa ambicioses per ésser realitzades" que Hurwicz va acabar per realitzar. Tot arrenca de la vella polèmica encetada els anys 30 sobre la possibilitat del socialisme per autors com von Mises, Hayek, Lange i Lerner. Von Mises sostenia que el mecanisme de mercat permetia de transmetre la informació i d'efectuar els càlculs per coordinar les decisions de tots els agents econòmics. Sense mercats ni propietat privada no hi hauria manera d'efectuar aquestes funcions. Lange va respondre amb un famós article argumentant que la utilització de preus no comportava necessàriament l'existència de mercats. En el fons, la qüestió radica en la possibilitat de construcció i de disseny de mecanismes de coordinació entre agents independents diferents del mecanisme dels mercats competitius.

A la darreria de la dècada dels cinquanta, Arrow i Hurwicz reconsideren el problema tot partint del fet que l'assignació eficient dels recursos en una economia descentralitzada requereix la solució d'un problema d'optimització. Visualitzen els mercats com a mecanismes de transmissió d'informació i de computació. Es pregunten si existeixen mecanismes alternatius. En un conegut treball conjunt, formalitzen el mecanisme de Lange i Lerner tot aplicant els processos de gradient. En aquest treball es porten molt més enllà les qüestions plantejades en els articles de programació i d'estabilitat i obren un panorama nou per a la teoria econòmica.

Aquest article és el punt de partida de tota un línia de recerca que tracta dels mecanismes de planificació econòmica.

El 1960 apareix l'important article sobre l'optimalitat i l'eficiència informacional dels processos d'assignació de recursos. Es construeix un marc analític en el qual es formalitzen els conceptes de mecanisme i de descentralització. Això dóna lloc a tota una sèrie d'articles en els quals el problema és la determinació de les quantitats mínimes d'informació que és imprescindible de transmetre per garantir una coordinació apropiada de les decisions dels agents econòmics. S'ha donat una atenció especial al disseny de mecanismes que funcionin correctament en entorns econòmics en els quals el mercat falla, tenint en compte explícitament les restriccions sobre les capacitats de transmetre i de processar informació.

## Mecanismes descentralitzats d'assignació de recursos: incentius

Els treballs que acabem de descriure donen a la informació un estatut epistemològic potser tan important com el de la divisió del treball. El problema econòmic no és només un problema de programació matemàtica, perquè hi ha molts agents que decideixen la coordinació de les seves accions per mitjà de processos de comunicació i que possiblement persegueixen objectius diferents. El 1972 i el 1973, Hurwicz publica dos articles en els quals hi afegeix un important element addicional: el comportament estratègic dels agents. Els agents poden ésser conscients dels efectes que els seus missatges tenen sobre les solucions del mecanisme i, per tant, escolliran els missatges en funció dels seus interessos. Es diu que un mecanisme és compatible amb els incentius individuals, si és present en l'interès de cada individu enviar els missatges i prendre les accions que més afavoreixin l'interès col.lectiu. La idea intuïtiva que als individus els podria convenir d'adoptar conductes diferents a les aconsellades per una assignació òptima dels recursos havia sorgit

en un article de Samuelson sobre la determinació de l'òptim en presència de béns públics. En aquest article, Hurwicz va fer veure que en una economia informacionalment descentralitzada, tot mecanisme defineix un joc no cooperatiu en el qual la informació que s'ha de donar és la principal variable estratègica. Va arribar de manera sorprenent a un teorema d'impossibilitat per dissenyar mecanismes compatibles amb els incentius individuals fins i tot en el cas que tots els béns de l'economia fossin béns privats. A partir d'aquesta contribució va aparèixer un enorme cos de literatura econòmica en què la qüestió dels incentius ocuparia un lloc cabdal. Amb tot això, la teoria dels jocs no cooperatius va experimentar una gran revifalla.

El professor Hurwicz ha fet contribucions importants a la teoria econòmica, no només tancant capítols, en donar solucions definitives a problemes, sinó també obrint nous camins que han fet canviar radicalment la visió de l'economista. Us he parlat, doncs, de Hurwicz, el científic.

Voldria parlar-vos també de Hurwicz, el mestre. Hem estat uns quants els que vam fer la tesi doctoral sota la seva direcció i molts els que es definirien com a deixebles seus. Què hem après? A més de la pura transmissió d'uns coneixements, ha sabut difondre una actitud metodològica sobre com "fer economia".

Hi ha tres aspectes fonamentals d'aquesta actitud. En primer lloc, la seva proverbial intolerància per les ambigüitats, pels conceptes mal definits i per la notació inapropiada. En segon lloc, la convicció de la potència de les matemàtiques com a llenguatge i instrument, no només per a la destrucció sistemàtica de pseudo-evidències, sinó també com a eina cabdal per a la definició d'estructures conceptuals noves que permetin una nova visió dels problemes econòmics. En tercer lloc, la consciència ben clara de les limitacions de la ciència en el seu estat actual. Parlava a classe que els resultats dels nostres models tenen la mateixa validesa que els experiments realitzats sobre

una raça de ratolins de laboratori, incapaços de sobreviure al món exterior. Ha demostrat diversos teoremes d'impossibilitat que estableixen les limitacions de la pròpia disciplina. Però la seva actitud ha estat sempre optimista i constructiva, potser perquè els anys quaranta, només arribar als Estats Units, va haver de treballar com a meteoròleg fent prediccions i es va adonar que també a les ciències naturals hi ha moltes dificultats de predicció. Els qui hem estat deixebles seus considerarem sempre el model formalitzat com una eina esmolada i penetrant. Però també sabem que els ganivets esmolats no s'han de deixar en mans de nens o d'insensats.

Parlaré finalment de Hurwicz, el savi. En contemplar la seva producció científica resulta sorprenent de constatar que els seus articles importants es publiquen quan ja ha fet els quaranta anys i segueixen a un ritme molt viu fins a l'actualitat. Tota la seva producció té un fil conductor sistemàtic, i per sota de l'aparent diversitat i especialització dels temes hi ha un disseny grandiós que ha modificat la visió dels economistes. Tradicionalment, l'economia com a ciència s'havia limitat a l'estudi d'un mecanisme concret d'assignació de recursos: el mecanisme del mercat. Amb Arrow i Hurwicz s'arriba a una nova etapa en la qual allò que era una dada del problema passa a ser una variable: el mecanisme d'elecció social o d'assignació descentralitzada de recursos, els processos de coordinació i compatibilització de les decisions d'agents independents i les mateixes institucions socials passen a ser objectes d'elecció. S'obren així nous camins i totes les institucions i organitzacions econòmiques, des de les empreses fins als contractes de tot tipus, són objecte d'anàlisi com a mecanismes d'interacció diferents del mercat perfectament competitiu. Aquests nous camins porten a indrets d'alta muntanya amb perspectives molt més àmplies. La teoria econòmica ha esdevingut, en mans de Hurwicz, un instrument de reforma social.

És per tot això, Excel.lentíssim i Magnífic Senyor Rector, com a reconeixement de la tasca realitzada per Leonid Hurwicz, el científic

eficaç i creatiu, el mestre que ens ha ensenyat economia i a fer economia, el savi que ha tingut com a fita el coneixement dels processos bàsics de l'entramat social, el reformador social que ha fet del canvi institucional l'objecte mateix de la seva recerca, que us demano que l'investiu Doctor Honoris Causa de la nostra Universitat Autònoma de Barcelona.

# ON MODELING INSTITUTIONS

BY

**LEONID HURWICZ**

## Introduction

In contrast to the 1930's when there seemed to be a gulf between economic theory and a recognition of the role of institutions in economic phenomena, much of the recent literature represents an effort to synthezise the two.

At least two streams of thought are involved. One of these has been focused either on specific institutions such as forms of land tenure (renting, sharecropping, wage labor), capitalism, socialism, or on problems such as vertical integration where institutional factors (e.g., property rights) play a crucial role. The contributions of Williamson, Stiglitz, Grossman, Hart, Holmstrom, Eliason, Kornai and others are among the outstanding examples, illustrating the diversity of issues studied. The other approach has aimed at developing a framework of sufficient generality to accommodate a wide spectrum of institutional arrangements and so to facilitate comparative as well as normative analytical work. The 1967 paper by Shapley and Shubik on ownership and the production function as well much of the theory of economic mechanisms may qualify in this category. A major contribution in this area is Schotter's study of social institutions.

The present paper must be classified as a further effort in developing a general framework but one having enough structure to provide a bridge to contributions of the first category. (A bridge between two streams is, of course, a metaphor of doubtful merit.) In particular, my aim is to suggest possible approaches to the modeling of institutions in a manner that is closely related to the theory of mechanisms. As the title indicates, my concern is with the appropriate structure of models to be used in the study of institutions, and the paper contains no new results. Furthermore, although I am primarily interested in economic institutions and mechanisms some of the considerations are of a more general nature and may be relevant outside of economics.

My basic objective, in a language that can be viewed as either figurative or mathematical, but which in any case oversimplifies

matters, is to define a 'space' whose various 'points' (or subsets) are distinct institutions. If one thinks of this space as characterized by many dimensions ('axes'), an institution is defined by specifying the values of various 'coordinates'. Of course, these coordinates may well involve nonquantitative attributes; indeed, that may be the typical situation.

The term 'institution' has two rather different meanings; (a) a set of rules or arrangements such as property rights, and (b) an entity such as an organization or office. Although some of the literature uses definitions broad enough to cover both, I prefer to maintain the distinction and to reserve the term 'institution' (sometimes 'institutional arrangement') for sense (a). Not surprisingly, however, we shall see that entities corresponding to sense (b) of the term play a very important role in the description of institutional arrangements.

Another distinction may be noted. One may be interested in institutions in the spirit of either positive or normative science. The positive science approach deals with explanations of the effects of institutions on various economic (and other social) phenomena and also with processes that result in the (endogenous) formation of institutions. But unless one were to deny the possibility of conscious acts and decisions that result in institutional change, there is also room for a normative or design point of view. Either of the two approaches can benefit from the availability of a rigorous framework in which to analyze institutional change, whether endogenous or designed.

No uniqueness or originality is claimed for the framework to be proposed in this paper. At best, I regard it only as a first step. It is not difficult to think of alternatives that have at least equal merit. For me, however, a natural point of departure is the theory of mechanisms In fact, to indicate the direction in which I am going, I shall regard an institution as a class of mechanisms[1] (with particular characteristics) —but with mechanisms conceived somewhat more broadly and endowed with more structure than has been customary.

In view of what has just been said, it is natural to start by devoting some attention to the concept and certain structural aspects of mechanisms. An this, in turn, may be introduced by the historical background. One source of interest in mechanisms is the standard 'neoclassical' microeconomics with its emphasis on market processes, especially those in perfectly competitive markets. The perfectly competitive market becomes the archetype of a mechanism. But since such a market cannot always exist (e.g. under increasing returns) or may be inefficient (e.g., in the presence of externalities), efficient alternatives are considered —for instance, marginal cost pricing with subsidies when increasing returns prevail, Pigovian taxes and subsidies for externalities, Lindahl solutions for public goods, etc. The search for such alternatives is motivated, in part at least, by the analysis of the mechanisms more likely to be encountered in such situations —monopoly, oligopoly, regulation, or a command economy—, with their various undesirable characteristics.

## Mechanisms

Particular mechanisms have, of course, a long history of formalization —a century and a half for oligopoly. But the formulation of a general theory of a mechanisms, of which the above examples could be regarded as special cases, is more recent.

*Two Models*. There are in fact two notions of a mechanism, interrelated but distinct. One of these, the *message model* (*'adjustement process'*), views a mechanism as exchange of information over time, followed (at terminal time of after aquilibrium has been established) by the outcome specified by a rule called 'outcome fuction'); the other, the *game model*, as a 'game form', that is a specification of actions available to the economic agents (called strategy or action spaces) and a rule specifiyng the consequences of actions (again called the outcome function). The particular game models used may be cooperative or non-cooperative; the latter lay be in normal or extensive form. Extensive form models

do pay attention to informational aspects and hence have points of contact with the message models.

*Message Model (Adjustement Process).* The message model specifies the signals ('languages' or individual 'message spaces', with the $i$-th agent's language denoted by $M^i$) that can be emitted by the agents as well as rules (called 'response functions') which specify the signals to be emitted by an agent given messages previously received and the information concerning both own and the others' characteristics. [An agent's characteristic, denoted $e^i$, specifies such data as the agent's preferences, endowment, and production possibilities. If the number of agents is $n$, the $n$-tuple of characteristics is called the *environnement* and is denoted by $e$. So $e = (e^1, \cdots, e^n)$.] An adjustment process is called 'privacy preserving' if an agent's response cannot directly utilize any information concerning the other agents' characteristics. Formally, with the $i$-th agent's response function denoted by $f^i$, the subscript representing points in time and the superscript referring to the agent, a privacy preserving process is governed by equations of the form

$$m^i_{t+1} = f^i(m^1_t, \cdots, m^n_t, e^i) \qquad i = 1, \cdots n;\ t = 1,2, \cdots$$

while in general (when the process is not privacy preserving) the right hand side could contain any of the components of the environment, hence any $e^j$ with $j \neq i$. Privacy preserving property of the response functions is intended to express part of the notion of informational decentralization of the adjustment process. In particular, perfectly competitive market can be modeled as having privacy preserving response fuctions.

An adjustment process is completely specified by the choice of the individual languages, response functions, and the outcome functions, written as $(M^1, \cdots, M^n; f^1, \cdots, f^n; h)$ where $h$ denotes the outcome function. The response functions may be imposed from outside or may have behavioral inperpretations, but the message

model does not analyze their origin —it takes them as given.Furthermore, once initial message values have been chosen, the adjustment process completely determines the final outcome. (A variant of this model uses multi-valued outcome functions; in that case there is an element of indeterminancy.)

*Game Model.* The situation is quite different in the game model. Here the model prescribes only the individual strategy domains $S^i$ (counterparts of the individual languages in the message model) and the outcome function. There is no exact counterpart of the response functions. Instead, the behavior of agents is postulated to be based on certain strategic calculations. If the game is non-cooperative, the most widely used assumption is that of Nash equilibrium where each agent maximizes his/her satisfaction given the others' strategy choices. However, alternative behavioral postulates are also often used such as 'refinements' of Nash equilibrium (subgame perfect, undominated, etc.) as well as non-Nash solutions such as maximin. Thus the game model mechanism [i.e., the game form $(S^1, \cdots, S^n;h)$] specified by the strategy domains $S^i$ and the outcome function $h$ is not sufficient to determine the outcome; one must also specify the behavioral postulate implicit in the choice of the game solution concept.

*Behavioral Postulates [non-strategic].* In fact, the behavioral postulates determining the choice of strategies by the agents need not be confined to game theoretic solution concepts. One could, for instance, postulate instead that this choice is determined by such factors as tradition, law, moral precepts, etc. It is important, therefore, to note that what we call the game model is of greater generality than the term seems to imply.

*Tâtonnement & non-tâtonnement.* One feature that the usual message models and extensive form game models have in common is that there are essentially two phases: 1. exchange of messages, resp. a sequence of moves, and 2. the realization of outcomes, resp. payoffs, following the last message (or the equilibrium message),

resp. the last move. This two phase structure corresponds to what in economics is called the Walrasian tâtonnement. Whatever its merits as an idealization of certain market phenomena, it is obviously too narrow as a description of how markets work. Indeed there have been constructed non-tâtonnement models of pure exchange in which goods change hands at each bargaining step. For our purposes, however, we shall need a structure encompassing both polar cases, but also permitting mixtures.

*Expanded Adjustment Process.* While in the earlier adjustment process with each time point $t$ is associated the $n$-tuple

$$m_t = (m_t^1, \cdots, m_t^n),$$

we shall now associate with each time point a triple $(m_t, a_t, z_t)$; here at represents actions at time $t$ and $z_t$ represents the outcomes materializing at time $t$. A similar generalization will be introduced into the extensive game, so that outcomes affecting preferences or utilities materialize before the final moves. (This is particularly appropriate, indeed seemingly unavoidable, in infinite horizon extensive form games.[2]) We shall refer to the first two components of the above triple simply as behavior at time $t$ and denote it by $b_t$. (In an extensive game messages and actions may be regarded as components of moves).[3] A reason for the generalization is to accommodate commitments (including contracts) and their fulfillment. Thus undertaking a commitment may be modeled as a message at time $t'$, while its fulfillment may be an action at a later time $t''$. If the commitment at time $t'$ is made by agent $i$, it will constitute a part of the content of $m_{t'}^i$. Hence, at a minimum, the language $M^i$ will have to be rich enough to specify an appropriate element of the action space as well as the timing of fulfillment. In this context, identifying actions and messages (as is often done) conceals the structure of commitment and fulfillment, matters of particular interest in the study of institutions.

A further enrichment of the structure is desirable in order that we should be able to refer to commitments or actions by groups (coalitions), i.e., various subsets of the set $\{1, \cdots, n\}$ of all players, as distinct form individual agents. Similary, commitments may be made by groups. An action by group $J$ taken at time $t$ will be denoted by $a\,(J,t)$. [Hence $a\,(i,t)$, where we write $i$ instead of $\{i\}$, is the same as $a_t^i$. Similary for messages and outcomes.] In addition to this role of groups, we shall also allow for the creation of, and participation by, artificial persons such as states, firms, labor unions, churches, etc.[4]

I shall defer until later the details that are necessary to represent specific features of the phenomena of commitment and fulfillment (or the consequences of non-fulfillment).

## Institutions as Classes of Mechanisms

Recent literature has many examples of modeling economic phenomena within the framework of standard ('un-enriched') versions of either of the two models —game or message exchange, and with institutional factors taken into account. Why then sould there be a need for a change in modeling? Basically because we want to be able to treat institutions as variables and need to define a space over which they can vary. Thus, for instance, the Arrow-Debreu model of a perfectly competitive market does not provide us with a natural way of considering other types of markets, and much less other economic systems such as command economies. By contrast, Stiglitz's paper on sharecropping defines a family of outcome functions with the worker's reward $r$ given by the formula $r=ay+b$ where $y$ is the worker's product (e.g., income generated by the worker) while $a$ and $b$ are numerical parameters. Various institutional arrangements can be defined by subsets of the two-dimensional parameter space $(a,b)$. Thus when $a = 1$ and $b < 0$ the worker is a renter; when $a = 0$ and $b > 0$, he/she is a wage-earner; ('pure') sharecropping is defined by $0 < a < 1$ and $b = 0$.[5] While the Stiglitz model treats many institutional aspects of the situation as constant, it

provides a most helpful illustration of the notion of a space of institutions.

In particular, we see that every point of the $(a,b)$-plane can be viewed as representing a conceivable mechanism. (Thus a particular sharecropping mechanism is defined by a pair such as (1/3,0) which specifies that the worker's share is 1/3).[6] Since each of the institutions under consideration is represented by a subset of the plane, it becomes natural to consider an *institution* as a *class of mechanisms*.[7] This idea is a point of departure for attempting a working definition of what we here mean by an institution and also for modeling institutions. Recalling that a (game model) mechanism is defined (in normal form) by a list of strategies and the outcome function, an institution is then specified by a set whose elements are the $(n+1)$-tuples $(S^1, \cdots, S^n;h)$.

*Restrictions on Outcome Functions and Strategy Domains.* The land tenure example distinguished institutions by varying the class of admissible outcome functions. Thus the institution of sharecropping is defined by all outcome functions of the form

$$r = ay,$$

with $a$ ranging between zero and one. Regulation (e.g., price control) illustrates the institutions defined by restrictions on the agents' strategy spaces rather than on the outcome functions. For instance, let $S^i$ represent the price to be set by agent $i$ (the seller). In the absence of regulation $S^i$ is the whole real axis, since the seller can sell at any price (positive, negative, or zero). On the other hand, when (maximum) price controls are introduced, a specific price ceiling prevails, say \$8/item; hence the *mechanism* prescribes $S^i$ as the set of all real numbers not exceeding 8. But the price control *institution* is defined by class of $S^i$'s each of which is an interval of real numbers of the form $(-\infty, k]$ where $k$ ranges over positive numbers.

*Additional Requirements.* While we view an institution as a class of mechanisms, it is of course not the case that every class of mechanisms is an institution. There are at least three additional aspects that must be introduced; (A) enforcement, (B) prior human actions, and (C) what I shall call 'universality'. [By 'universality' I here mean that the rules are meant to apply not just to a particular person or group of persons at a particular point in time, but rather to a category of situations and persons, thus applying to all persons and situations qualifying in such categories, with the rules intended to remain valid over an extended (often not limited in advance) period of time.][8]

## Enforcement

*Usual Implicit Assumption: Game Form Prevails.* The issue of enforcement raises analytical problems that can be only mentioned here. Looking first at standard mechanism theory, it is implicit in the usual interpretations that a given game form prevails. That means that the players will not use strategies outside of the prescribed domains $S^i$ and that, once the strategies have been chosen, the consequences will be those specified by the outcome function. Now given the assumption that the prescribed game form will prevail, and if one regards Nash equilibrium (possibily in 'refined' form) or some other non-cooperative game solution as behaviorally realistic, it is possible to regard the equilibrium configuration ($n$-tuple) of the players' strategies as self-enforcing.

The assumption that a particular game form prevails (i.e., is abided by the players) may be plausible if the strategy domains are only limited by physical (or similarly unavoidable) factors, and where the outcome function represents laws of nature. But that is far from being the case in game forms that have been designed to implement certain social goals, as for instance in the mechanism for allocation of public goods due to Groves and Ledyard, Hurwicz [1979b,c], and Walker, or in the mechanisms for the implementation of the Walrasian correspondence (i.e., the attainment of perfectly competitive equilibrium allocations) proposed by Schmeidler,

Maskin, Postlewaite and Wettstein, and others, including myself. In such models we, for instance, limit the participants to proposing prices and quantities or numerical messages, while (as in Schemidler's mechanism) the actual flow of goods may involve a specified form of rationing when proposed demand exceeds supply. One must ask why the players would voluntarily abide by the requirements of the game form or how they could be induced to do so. A similar question arises with regard to the Groves and Ledyard mechanism, especially because it is no individually rational. (I.e., unlike in a mechanism implementing the Lindahl correspondence, an individual might be worse off at the end than he/she was before the game.) Unless forced to, some individuals might prefer not to participate, especially if they had enough information to anticipate that they woult be the losers in equilibrium. But even when individual rationality is satisfied, e.g., when the game form implements the Lindahl correspondence, some players might prefer not to abide by the rules of the game form.

*Augmented vs. Primary Game.* It is then natural to think of introducing an element of enforcement into the situation. This can be viewed as creating an *augmented game* consisting of the *primary game* (say the game form defined by Groves and Ledyard) plus a policing system specifying penalties for transgressions and providing incentives to a set of additional[9] players (policemen, judges, etc.) to prevent or punish transgressions.[10] Of course, the same questions that were raised with regard to the primary game can also be raised with regard to the augmented game. It would be fortunate (although very unlikely) if the (say Nash) equilibrium of the augmented game were such that it succeeded in inducing the primary game agents to obey its rules. Even then, the augmented game would no longer be implementing the ('original') social choice (goal) correspondence because the enforcement apparatus costs resources. In practice one typically settles for a trade-off between the degree ot imperfection in the enforcement of the primary games rules (say of tax law) and the cost (or even feasibility) of enforcement. One can also consider an augmentation of the augmented game (a second-order augmented game) which would provide for the

policing of the enforcers of the primary game, and so on. But the problem would reappear at the next stage. Thus any proposal to redesign ('reform') a social institution (say an economic system) —which in our interpretation involves changing the class of admissible game forms— raises questions of enforcement, its feasibility, cost, as well as 'side-effects' involving various societal values.[11]

*Enforcement in 'Organically Emerging' Intitutions.* The apparent need to introduce an enforcement system is by no means confined to artificially designed mechanisms. In fact, the point is emphasized by Schotter (p. 11) in his informal definition which characterizes a social institution as "a regularity in social behavior that is agreed by all members of society, specifies behavior in recurrent situations, and is either self-policed or policed by some external authority". He illustrates the need for an external enforcing authority (here the state) by the system of property rights, a social institution. The importance of the example lies in the fact that it is regarded as one of the institutions "that emerge organically by human action but not by human design..." (Schotter, p. 28). Indeed, both the emergence of a system of property rights and of the enforcing state are viewed as due to such an 'organic' process.

## Artificial (Juristic) Persons

One byproduct of the preceding discussion is the emergence of the role of the state or other bodies whose function is to enforce or police the rules. The phenomenon is of importance not only in the context of the enforcement process but also because it introduces a potential new participant in the social processes —an *artificial person*, of which a 'juristic person' is a special case. Of course, this concept is much broader than that of a state or enforcement agencies; corporations and labor unions are among instances of particular interest to the economist. Although there are obvious distinctions to be drawn between natural and artificial persons, it is important to recognized that the latter should for many purposes be regarded as separate players. That is the case even for situations where there is

an office (say that of the President of the United States) occupied by a single (natural) person; indeed there may be a conflict between the two. Actions taken in the name of the office (even though carried out by the occupant) are distinct from those taken in the name of the occupant as a natural person. As this example illustrates, one should not identify the notion of an artificial person with that of an organization, although usually an organization is an artificial person.

*Mission and Agency*. An important characteristic of such bodies as enforcement entities or ombudsmen is that they have a role or *mission* in the institutional design: to make the system implement (or at least come closer to implementing) some social goals. It would be convenient to have a special term for such entities, perhaps *agencies*. [I am not sure how close this notion of an agency is to the second meaning (listed as (b) in the introductory section above) of the term 'institution', as applied for instance to an entity such as a university (rather than to a phenomenon such as the system of property rights).] When new institutional arrangements are introduced it is usual that an agency is at the same time created to help implement[12] these arrangements. The role of the agency is often to specify the 'parameters' that would (in the terminology of this paper) convert an institution (i.e., a class of game forms) into a mechanism (i.e., a game form), as well as to help enforce the rules of the mechanism. Examples, especially from the regulatory field, abound. Price controls and anti-trust are among the obvious ones.

Once the role of artificial persons and agencies is recognized, the internal structure of the game form must be sufficiently enriched to accommodate the formation, activities, and even demise of these entities. In particular, the message space must be rich enough to accommodate a variety of individual and group commitments, with or without built-in contingencies.

## Formation through Prior (Human) Action or Behavior

A second essential feature in the concept of an institution as a class of admissible mechanisms (game forms) is that it comes into

existence through prior (usually collective) human action or behavior. Since some moves or behaviors are physically or physicologically ruled out, this means that not all restrictions on admissibility of mechanisms are institutional in nature. Descriptively, these prior actions may take the form of legislation or the adoption of customs or ethical norms. Within the framework of game theory there are various possibilities of formalizing the process of institution formation.

*Reiter/Hughes Two-Game Model.* The route chosen by Reiter and Hughes in modeling regulation was to postulate a sequence of two games. The first one is a cooperative game representing the political process (say congressional legislation) which formulates the rules of the regulatory process. The second is a non-cooperative game of incomplete information (with economic agents and regulators as players) in wich the specific regulations are arrived at. An alternative might have been to combine the two games of the Reiter and Hughes model into a single one, presumably a non-cooperative game in extensive form, with the earlier moves correspondig to their first game.[13] Reiter and Hughes also consider the dynamic aspects of regulatory phenomena taking into account the effects of changes in the (economic) environment (e.g., capital formation, technology), both exogenous and those due to the regulation. Hence, except initially, both games are being replayed.

*Supergame.* This suggest modeling the process as a supergame, of which institution formation and the actual regulatory process operate at all points of time. A possible difficulty with the supergame approach lies in the fact taht the cast of players changes over time, so that there is imperfection of memory and some of the customary threat/reward strategies are not applicable.

*Sequences of Games.* It therefore seems not without interest to consider a compromise in which there is enough myopia so that the dynamics is in the nature of a sequence of games, though possibily with some memory from (say) one game to the next. Hence both game and adjustment process elements are present. Certain elements of such a model were described in Hurwicz [1987a] and will be briefly sketched in what follows.

We consider an infinite sequence of time intervals (perhaps in some respects reminiscent of Hicksian weeks). During each week an extensive form incomplete information game is played with a finite number of moves, say $t = 0,1,\ldots,T$. [A more complete notation would use a pair, say $(t, \tau)$ where $\tau$ is the week and $t$ the move number during that week.] There may be some memory from one week to another which might, for instance, be used to affect a player's conjectures about the other players' characteristics, but still each period is viewed as a separate game.[14] However, the dynamic phenomena recognized by Reiter and Hughes would be present, and —in priciple— the model could lend itself to a study of convergence, trends, cyclicities, etc.

(*Commitments*.) A week is viewed as long enough so that any commitments (including contracts) made during a week are (or at least supposed to be) carried out during the same week. (Hence a year or a decade might have been a better label for this time period!) Let $N = \{1, \cdots, n\}$ denote the set of players. [To simplify notation we shall ignore the fact that artificial persons may be created during the week, so that the set of players will in fact vary from move within the week.] Denote by $K$ any nonempty subset of $N$, i.e., a group or a coalition. The behavior of the group $K$ at $t$-th move is denoted by $b(K,t)$; it has two components: the message $m(K,t)$ and the action $a(K,t)$; the outcome (say resource allocation)[15] for the group $K$ at the $t$-th move is $z\ (K,t)$ These outcomes may generate utilities at every move —not merely at the end. Hence this is not in general a tâtonnement process, although tâtonnement is a legitimate special case.

*Enforceability*. To make matters easier we initially avoid the consideration of an augmented game (with an enforcement sector), but in order to permit moderately realistic tratment of commitments (again including contracts) we classify actions according to whether

they are enforceable. For each (move) $t$ we define the set $A(t)$ of mutually compatible actions, with

$$A(t) = \{\ a\ (K', t), a\ (K'', t, \cdots ):\qquad \}$$

as the set of mutually compatible actions by the various groups. [In the above notation we assume a complete listing of all the subsets of $N$, with $K'$ the first elements of that list, $K''$ the second, and so on. The empty space after the colon would have to be filled with a specification of the spaces over which these mutually compatible actions can range.] We would then postulate set of actions $L(K,t)$ enforceable on $K$ at move $t$ (within $A(t)$).

*'Bounded Rationality' Modeling.* In models delaing with the institution of ownership complexity (or other aspects of 'bounded rationality') is invoked to explained the incompleteness of contracts, and it is desirable to model this explicity. A crude way of doing this starts with a set $C(t)$ of contingencies that can be envisaged at $t$. The idea that there are limits on how much detail concerning contingencies can be built into a contract is expressed by postulating a partitioning $\Gamma(t')$ of the set $C(t)$. Two contingecies belonging to the same set of this partition are considered formally (say for purposes of legal proof) indistinguishable. (This may correspond to some of the considerations in Williamson as well as in Grossman and Hart.) Similary, we postulate a partitioning $\Sigma\ (K, t)$ of the set of enforceable actions, with the interpretation that two actions belonging to the same set of the partition are considered as formally equivalent. These phenomena of indistinguishability or equivalence may mean that one of the parties has a choice of interpretation as to which contingency or enforcement action is appropriate. The equivalences thus permit certain agents to acquire residual powers of the sort that Grossman and Hart associate with ownership, but which also characterize the discretionary powers of bureaucrats or party organizations in countries such as P.R.C. or S.U.

*Commitment: Consistency Requirements.* A commitment (in particular a contract) is viewed as a part of a message consisting of a 'flag' (signaling formal commitment) and a functional relation whose argument is a contingency and whose value is a set of (presumably) feasible actions. A commitment (contract) entered into by group $K$ at move $t$ is a part of the message $m(K,t)$. In principle, this function should be constant on the (indistinguishable) elements of the partition $\Gamma(t')$ where $t'$ is the time at which the commitment is to be carried out. Let this function be written as $\varphi_K(c,t,t')$ where $t$ is the time the commitment is made, $t'$ when it is to be carried out and $c$ is a contingency. Let its value, i.e., the set of actions from which fulfillment must be selected at time $t'$ by the group $K$ be denoted by $D(K,t')$. To be properly enforceable this set should be the intersection of the feasible set $A(K,t')$ with a set of the partition $S(K,t')$. However, in fact the function may not satisfy the preceding consistency requirements, and so leave ambiguities to be either resolved by legal procedures or by the residual power of certain participants.

*Residual Power.* The specification of such residual powers is an essential element distinguishing the institutional structures of various societies. There is an interesting parallelism between the role played in institutional structure by such power residuals and the role played in institutional structures by the location of residual risks (as in the land tenure example). In fact, these examples suggest a possible further narrowing down of the definition of an institution to express the qualitative differences that make one label two situations as being to different institutional arrangement. It is as if institutions corresponded to subspaces being defined by fixing the values of a (typically finite) number of coordinates. (Hence even if the space of mechanism were infinite-dimensional, an institution would correspond to a subplace (more generally, subset) of finite codimension.) The fixed values would typically be zeros or ones.

*My Motivation.* It should be clear that the sort of model suggested in the preceding paragraphs would not displace the more specific models present in the literature of which some examples

have been cited above. The aim is rather to provide a framework in which such models could be embedded, so as to facilitate comparative or normative approaches. In particular a target is to develop an implementation[16] theory whose products (proposed institutions or mechanisms) would be framed within the same universe of discourse as, and took into account the limitations that are encountered in actual efforts toward institutional change currently observed in many countries, both capitalist and communist, such as measures toward deregulation, privatization, and the substitution of markets for for bureaucratic procedures. In the normative sphere such a development would presumably be of the 'second best' type,[17] less satisfying but more realistic. It could also be helpful in the realm of positive theory aimed at explaining current and past observed phenomena.

## References

(This list includes work relevant to the paper although not specifically cited.)

Atkins, W. E., et al. [1931] *Economic Behavior: An Institutional Approach, volume 1* (by members of the Department of Economic, Washintong Square College, New York University). Cambridge, Houghton Mifflin Company 1931.

Bardhan, P., ed. [1988] "Chapter One." *The economic Theory of Agrarian Institutions*, Oxford University Press.

Commons, J. R. [1924] *Legal Foundations of Capitalism*. New York, McMillan 1924.

Commons, J. R. [1934] *Institutional Economics*. New York, McMillan 1934.

Commons, J. R. [1951] *The Economics of Collective Action*. New York, McMillan 1951.

Dow, g. k. [1988?] "Contractual and Strategic Perspectives: A Reply to Williamson." University of Alberta, mimeo.

Eliason, G. [1987] "The economics of Institutions and Markets - The organization of Research at IUI," in *IUI Yearbook 1986-1987*, The Industrial Institute for Economic and Social Research Research.

Grossman, S. J. and O. D. Hart [1986], "The costs and benefits of ownership: A theory of vertical and lateral integration. "*Journal of Political Economy*, 94: 691-719.

Groves, T. and J. Ledyard. [1977] "Optimal allocation of public goods: A solution to the 'free rider' problem," *Econometrica*, 45: 783-811.

Hart, O. and B. Holmstrom. [1987] "The theory of contracts," in *Advances in Economic Theory, Fifth World Congress*, T. Bewley(ed.). Cambridge University Press 1987.

Hart, O. and J. Moore. [1988] "Property rights and the nature of the firm." Working paper no 495, Economic Dept. MIT.

Hicks, J. R. [1939] *Value and Capital.* Oxford, Clarendon Press.

Holmstrom, B. and R. B. Myerson. [1983] "Efficient and Durable Decision Rules with Incomplete Information." *Econometrica*, 51.

Hurwicz, L. [1960] "Optimality and informational efficiency in resource allocation processes." *Mathematical Methods in the Social Sciences*, eds. K. J. Arrow, S. Karlin, and P. Suppes. Stanford, Stanford University Press 1960.

Hurwicz, L. [1972a] "Organizational structures for joint decision making: A designer's point of view." *Interorganizational Decision Making*, eds. M. tuite, R. Chisholm, and M. Radnor, Chicago, Aldine Publishing Co., 1972, pp 37-44. (Second edition, Minneapolis: University of Minnesota Press, 1986.)

Hurwicz, L. [1979a] "On allocations attainable through Nash equilibria." *Journal of Economic Theory* 21: 140-165. Also in: *Aggregation and Revelation of Prefrences*, J. -J. Laffont. Amsterdam, North-Holland 1979.

Hurwicz, L. [1979b] "Outcome Functions Yielding Walrasian and Lindahl Allocations at Nash Equilibrium Points." *Review of Economic Studies*, Vol. XLVI (2).

Hurwicz, L. [1979c] "Balanced Outcome Functions Yielding Walrasian and Lindahl Allocations at Nash Equilibrium Points for Two or More Agents." *General Equilibrium, Growth, and Trade*, edited by J. Green and J. Scheinkman, Academic press.

Hurwicz, L. [1987] "Inventing new institutions: The design perspective." *American Journal of Agricultural Economics* 69: 395-402.

Hurwicz, L. [1987] "Mechanisms and Institutions," presented at the International Economic Association Tokyo Round Table Conference, September 1987. (To be published in the *Proceedings of the International Economic Association.*)

Knight, F. H. [1952] "Institutionalism and empiricism in economics." *American Economic Review*, Papers and Proceedings Supplement 42: 45-55

Kornai, J. [1986a] "The Hungarian reform process: Visions, hopes, and reality." *Journal of Economic Literature* 24: 1687-1737.

Kornai, J. [1986b] "Contradictions and Dilemmas." *Studies on the Socialist Economy and Society*, MIT Press.

Lagunoff, R. [1988] "Fully endogenous mechanism selection and the Coase theorem," mimeo, University of Minnesota, April, 1988.

Kornai, J. [1986] "Contradictions and Dilemmas." *Studies on the Socialist Economy and Society*, MIT Press.

Marschak, T. and S. Reichelstein. [1986] "Informationally efficient hierarchies," mimeo, University of California, Berkeley, May 1986.

Maskin, E. [1977] "Nash equilibrium and welfare optimality." Working paper MIT, Cambridge.

Postlewaite, A. and D. Wettstein [1983] "Implementing constrained Walrasian equilibria continuously." Penn. CARESS Working paper 8324, University of Pennsylvania, October, 1983.

Reuter, S. and J. Hughes. [1981] "A Preface on modeling the regulated U.S. economy." *Hofstra Law Review*, 9 (5)

Reiter, S. [1977] "Information and performance in the (new) welfare economics." *American Economic Review* 67: 226-234. Also in: *Studies in Mathematical Economics*, ed. Stanley Reiter. Washintong, Mathematical Association of America 1986.

Ruttan, V. W. [1978] "Induced institutional change," in *Induced Innovation*, H.P. Binswanger and V.W. Ruttan (eds.), John Hopkins University Press.

Ruttan, V. W. [1984] "Social Science Knowledge and institutional change." *American Journal of Agricultural Economics*: 549-559.

Schmeidler, D. [1980] "Walrasian analysis via strategic outcome functions." *Econometrica* 48: 1585-1594.

Schotter, A. [1981] *The Economic Theory of Social Institutions.* Cambridge University Press, Cambridge.

Shapley, L. and M. Shubik [1967] "Ownership and the production function." QJE.

Stiglitz, J. E. [1974] "Incentives and risk sharing in sharecropping." *Review of Economics Studies*, 41:219-256.

Walker, M. [1981] "A simple incentive compatible scheme for attaining Lindahl allocations." *Econometrica*, 1981

Weitzman, M. L. [1974] "Prices vs. quantities." *Review of Economics Studies* 41: 477-491

Williamson, O. E. [1975] *Markets and Hierarchies*, The Free Press.

Williamson, O. E. [1985] *Economic Institutions of Capitalism: Firms, markets, Relational Contracting*. The Free Press.

## Notes

[1] An alternative approach is adopted by Schotter (1981, p. 29) who views social institutions ..."not [as] part of the rules but part of the solutions to iterated games of strategy." Let us note, however, that the concept proposed in the present paper views an institution not as a set of rules of a game to be played but rather as a set of restriction on what rules are admissible. The latter distinction could perhaps be avoided (by redefining the nature of the game to be played), but at the cost of losing some transparency in the phenomena being studied.

[2] I am indebted to Ehud Kalai for enlightenment on this point.

[3] A generalization of this type, with an element of 'on line' operations was suggested by Thomas Marschak several years ago in paper presented at a decentralization conference.

[4] The distinction between actions by groups and by artificial persons may seem unnecessary, but I regard is a useful when trying to relate on the one hand to structures of game theory (especially cooperative games) and those of law with its ways of treating certain entities as if they were persons. The role of action by collective bodies was among the main points stressed by Commons.

[5] To use an analogy, suppose we have a macro-economic model in which the rate of interest r plays a role. One might use a particular value of the rate of interest, say 7%, and analyze the workings of such a model. This would not be ignoring the role of the rate of interest, but it would not enable us to analyze the consequences of its changes. Moreover, if we just inserted .07 wherever the rate appeared without indicating that it is a particular value of a variable r, the user would have no way of knowing how to use such a model to consider alternative values of the variable r. This may seem belaboring the obvious, but the distinction between introducing into the model a particular institution as a 'constant' on the one hand and treating it as a particular value of a variable is crucial; the analogy may help make the point clearer.

[6] Alternatively, when agents are free to choose such parameters as wage rates by voluntary agreement, it is more natural to view the whole set of points $W = \{(a, b) : a = 0, b > 0\}$ as corresponding to the wage earning mechanism. However, the full description of the arrangement would require the specification of various legal or customary rules governing the nonmonetary aspects of the wage contract, rules not subject to modification by the contracting parties. One may think of such rules as points on a third (nonnumerical) axis, the $z$-axis. Rules compatible with the notion of a wage contract constitute a subset Z' on this axis. A particular wage mechanism is defined by a pair $(W, z^*)$ where $z^*$ is a particular point belonging to Z'. The institution of wage earning is then defined as the collection of all such pairs, i.e., by the set $\{W, z) : z \text{ in } Z'\}$.

[I am indebted to Stanley Reiter for enlightening comments concerning these issues.]

[7] Another reason for thinking of an institution as a class of mechanisms is that a mechanism typically refers to only some aspects of people's activities (e.g., work and rewards) while other aspects (say leisure activities) remain outside the mechanism model.

[8] The definition given by Schotter (p. 11), as well by Lewis (quoted in Schotter, p. 9), refers to behavior 'in recurrent situations'. It would seem that universality with respect to persons affected is also a significant feature.

[9] It is not necessary to have additional players as enforcers. The primary players may be motivated to play that role themselves. Honor codes are one example; societies where citizens are encouraged to spy on and denounce one another also illustrate the fact that the primary players can have a role in the process of enforcement activity was completely carried out by the primary players without any outside enforcers, the incentive structure required to induce such behavior would ordinarily imply that the goal function of the primary game would no longer be implemented.

[10] I have benefitted from a conversation with Andrew Postlewaite concerning problems of modeling enforcement.

[11] This does not mean that analysis ignoring enforcement problems is without value. In particular, various impossibility theorems based on the implicit assumption that the game forms can be costlessly enforced are likely to be a fortiori valid when the enforcement issues are raised. Also, there may be situations where there are obvious reasons to expect that the participants will abide by the rules of the game form without any additional enforcement apparatus. Finally, it may sometimes be adequate to recognize the cost imposed by the need for enforcement without having to consider explicitly the way in which the augmented game differs from the primary game.

[12] This use of the term 'implement' is closer to the usual meaning than that introduced by Maskin.

[13] But: in a multi-period world, institutions last over many periods!
[14] In particular, institutions persist from week to week.
[15] Taking account of operating (hence transaction) costs.
[16] In the usual (non-Masking) sense.
[17] In particular, because of operating costs.

# CURRICULUM VITAE

DE

# LEONID HURWICZ

Leonid Hurwicz

Permanent position: Regents' Professor of Economics Emeritus
Department of Economics. University of Minnesota.
Currently (1988-89): Visiting Professor in the Departments of Economics and Managerial Economics & Decision Sciences. The center for Math Studies. Northwestern University.
Leverone Hall, 3-014
Evaston, IL 60201.

**Born**: August 21, 1917; Moscow, Russia.

**Citizenship**: United States.

**Marital Status**: Married.

**Number of Children**: four.

## Education

University of Warsaw, LL.M.: 1938.
London School of Economics: 1938-39.
Institut des Hautes Études Internationales, Geneva, Switzerland: 1939-40.
Harvard University: 1941.
University of chicago: 1940-42.

## Academic Honors

Fellow in Economics, Harvard University: 1941 (Fellowship awarded, but not accepted by L. Hurwicz).
Guggenheim Fellow: 1945-46.
Sigma Xi: 1946.
Fellow, Econometric Society: elected 1949.
Fellow, center for Advanced Study in the Behavioral Sciences: 1955-56.
The Fisher Lecturer on Economic Theory, Joint European Conference of the Institute of Mathematical Statistics and the Econometric Society, Copenhagen: 1963.

Member, American Academy of Arts and Sciences: elected 1965; member, Midwest Council: 1979-85, National Council since 1985.
President, Econometric Society: 1969.
Ely Lecturer, American Economic Association meetings, Toronto: 1972.
Member, National Academy of Sciences: elected 1974.
Distinguished Fellow, American Economic Association: elected 1977.
Member, Academy of Independent Scholars: 1979.
Honorary Degree, Doctor of Science, Nortwestern University: June 1980.
Distinguished Guest Speaker, Western Economic Association Meetings: June 1980.
Councilmember, Economic Society: 1982.
Honorary Professor of Central China University of Science and Technology, Wuhan, Hubei, People's Republic of China: 1984.
Keynote speaker, C. Woody Thompson Lecture, at Midwest Economics Association: April 1988.

## Current Position

Regents' Professor of Economics Emeritus, University of Minnesota: 1988.
Visiting Professor in the Departments of Economics and Managerial Economics & Decision Sciences, Nortwestern University: 1988-89.

## Past Positions

Research Assistant, MIT: 1941 (Economics).
Research Associate, University of Chicago: 1942-44 (in Meteorology).
Research Associate, Cowles Comission for Economic Research: 1944-45.
Associate Professor and Professor, Iowa State College, Ames: 1946-49.
Professor of Economics and Mathematical Statistics, University of Illinois: 1949-51.
Visiting Professor, Cowles Commission, University of Chicago: 1949-50.
Professor of Economics and Mathematics, University of Minnesota: since 1951.
Visiting Professor, Stanford University: 1955-56 and 1958-59.

Chairman, Statistics Department, University of Minnesota: 1961-63.
Visiting Lecturer, Bangarole University (India), Fulbright Grant: 1965-66.
Frank W. Taussing Research Professor (Visiting), Harvard University: 1969-70.
Visiting Professor of Economics, Harvard University: 1970-71.
Visiting Professor of Economics, University of California, Berkeley: 1976-77.
Visiting Professor of Economics, Tokyo University: 1982.
Coordinator, Economics Program, Institute for Mathematics and Its Applications: 1983-84.
Sherman Fairchild Distinguished Scholar, California Institute of Technology, Pasadena: 1984-85.
Lecturer, People's University, Beijing, China: Spring 1986.
Regents' Professor of Economics, University of Minnesota: 1969-1988.

## Other Experience

Consultant, Weather-Wing, U.S. Air Force: 1944.
Consultant, Cowles Commission: 1946.
Consultant, U.S. Bureau of Standards: 1947.
Member, Research Division, U.N. Economic Commission for Europe: 1948.
Consultant, Rand Corporation: 1949.
Consultant, U.S. Bureau of the Budget: 1950-51.
Member, National Research Council of the National Academy of Sciences: 1954-57.
Associate Editor, *International Economic Review* :1959-71.
Consultant, U.S. Office of Science and Technology: 1963-64.
Member, NSF Commission on Weather-Modification: 1964-65.
Consultant, HEW National Center for Health Services Research and Development: 1968.
Director, North Star Research Institute, Minneapolis: 1963-75.
Associate Editor, *Journal of Economic Theory* :1969-70.
Member, Nuclear Proliferation and Safeguard Advisory Panel, Office of Technology Assessment: 1976-79.

Member, Panel on Legislative Impact on the Courts, Committee on Research on Law Enforcement and Criminal Justice, National Research Council: 1977-80.

Member, Advisory Board, *Journal of Mathematical Economics*: since 1974.

Member, Editorial Board, *Journal of Comparative Economics*: 1977-82.

Member and Advisor, Journal Committee of the Indian Statistical Institute, Calcutta, India: 1978.

Consultant, Advisory Committee on Information Science and Technology, National Science Foundation: 1979-81.

Member, Repport Review Committee, National Academy of Sciences: 1979-85.

Member, Repport Review Committee, National Academy of Sciences: 1981-85.

Member, Committee on Basic Research in Social and Behavioral Sciences of the National Research Council: 1982-86.

Seminar Lectures at Beijing University and Nankai University: Fall, 1982 and Summer, 1984.

Member, Commission on Behavioral and Social Sciences and Education of the National Research Council: since 1983.

Discussant at the Cato Institute's conference, "Planning America: Government or the Market?": April, 1984.

Distinguished Scholar Exchange Program, Committee on Scholarly Communication with the People's Republic of China, National Academy of Sciences, Seminar Lectures at Universities in Beijing, Tianjin, Xi'an, Wuhan, and Canton: Summer 1984.

Member, Editorial Board, *Journal of Complexity*: since 1985.

Member, Editorial Board, *International Journal of Development Planning Literature*: since 1985.

Member, Social Sciences/Humanities Panel of the Committe on Scholarly Communication with the People's Republic of China of the National Research Council: since 1988.

Visiting Scholar in Decentralization Theory, Interuniversity Center for Economics, University of Indonesia, Jakarta, Indonesia: August 1988.

## Publications

"Scholastic Models of Economic Fluctuations," *Econometrica*, April 1944.

"The Theory of Economic Behavior," *American Economic Review*, December 1945.

"Theory of the Firm and Investment" *Econometrica*, April 1946.

"Some Problems Arising in Estimating Economic Relations," *Econometrica*, July 1947.

"Linear Programming and General Theory of Optimal Behavior," (abstract), *Econometrica* 17, April 1949.

"Generalization of the Concept of Identification," in T.C. Koopmans, ed., Statistical Inference in Dynamic Economic Models. John Wiley and Sons, Inc., New York 1950.

"Prediction and Least Squares," *Ibid.*

"Variable Paramenters in Stochastic Processes: Trend and Seasonality," *Ibid.*

"Least-Squares Bias in Time Series," *Ibid.*

"Some Implications of Electronic Thinking Organisms" Current Economic Comment, 12 (2) May 1950.

"Theory of Economic Organization" (abstract), *Econometrica*, 1951.

"Some Specification Problems in Applications to Econometric Models" (abstract), *Econometrica*, July 1951.

"Aggregation in Macroeconomic Models," (abstract), *Econometrica*, July 1952.

"What Has Happened to the Theory of Games?" *American Economic Review*, May 1953.

"Decentralizated Resource Allocation," Cowles Commission Discussion Paper: Economics No. 2112, May 1955.

"Input-Output Analysis and Economic Structure: Review," *American Economic Review*, September 1955; Correction December 1955.

*"Reduction of Constrained Maxima to Saddle-Point Problems," (with Kenneth J. Arrow), *Proceedings of the Third Berkeley Symposium on Mathematical Statistics and Probability*, Jerzy Neyman, ed., University of California Press, Berkeley and Los Angeles, 1956.

"Resource Allocation as a Dynamic Process," *Econometrica*, April 1957.

*"Gradient Methods for Constrained Maxima," (with Kenneth J. Arrow), *Operations Research*, April 1957.

*Studies in Linear and Non-Linear Programming*, edited by Kenneth J. Arrow, Leonid Hurwicz, and Hirofumi Uzawa, Stanford University Press, 1958.

"Programming in Linear Spaces," *Studies in Linear and Non-Linear Programming*, edited by K. Arrow, L. Hurwicz, and H. Uwaza, Stanford University Press, 1958.

"A Note on the Lagrangian Saddle-Points," (with Hirofumi Uwaza), *Ibid.*

"Gradient Method for Concave Programming, I: Local Results," (with Kenneth J. Arrow), *Ibid.*

"Gradient Method for Concave Programming, III: Further Global Results and Applications to Resource Allocation," (with Kenneth J. Arrow), *Ibid.*

*"On the Stability of the Competitive Equilibrium I," (with Kenneth J. Arrow), *Econometrica*, October 1958.

*"On the Stability of the Competitive Equilibrium II," (with Kenneth J. Arrow and H. D. Block). *Econometrica*, January 1959.

*"Optimality and Informational Efficiency in Resource Allocation Processes" *Mathematical Methods in the Social Sciences*, edited by Kenneth J. Arrow, Samuel Karlin, and Patrick Suppes, Stanford University Press, 1960; also in: K. J. Arrow and T. Scitovsky, eds., *Readings in Welfare Economics*, Irwin, 1969.

*"Competitive Stability Under Weak Gross Substitutability: The 'Euclidean Distance' Approach" (with Kenneth J. Arrow), *International Economic Review*, January 1960.

*"Some Remarks on the Equilibria of Economic Systems" (with Kenneth J. Arrow), Econometrica, July 1960.

*"Decentralization and Computation in Resource Allocation" (with Kenneth J. Arrow), *Essays in Economics and Econometrics*, edited by Ralph W. Pfous, University of North Carolina Press, 1960.

*"Stability of the Gradient Process in *n*-Person Games" (with Kenneth J. Arrow), *Journal Soc. Indust. Appl. Math.*, 8, June 1960.

"Conditions for Economic Efficiency of Centralized and Decentralized Structures," *Value and Plan, Economic Calculation and Organization in Eastern Europe*, edited by Gregory Grossman, University of California Press, 1960.

*"Constraint Qualifications in Maximization Problems" (with Kenneth J. Arrow and Hirofumi Uwaza), *Naval Research Logistics Quarterly*, June 1961.

"On the Structural Form of Independent Systems," in *Logic, Methodology, and Philosophy of Science*, edited by E. Nagel, P. Suppes, and A. Tarski, Stanford Univesity Press, 1962.

*"Competitive Stability Under Weak Gross Substitutability: Non-Linear Price Adjustment and Adaptive Expectations" *International Economic Review* 3, 1962.

"Discussion: Analytic Framework for Measuring Social Costs" *Journal of Farm Economics*, December 1962.

"Basic Mathematical and Statictical Considerations in the Study of Rhythms and Near Rhythms," *Annals of the New York Academy of Sciences*, 98, 1962.

"Mathematics in Economics: Language and Instrument," *Mathematics and the Social Sciences*, edited by J. Charlesworth, Philadelphia, 1963.

"On Decentralization in the Presence of Externalities," paper presented at the Econometric Society Meeting, San Francisco, 1966.

"Programming Involving Infinitely Many Variables and Constraints," Activity Analysis in the Theory of Growth and Plannig, edited by E. Malinvaud, and M. O. L. Bacharach, St. Martin's Press, 1967.

"On the Concept and Possibility of Informational Decentralization," *American Economic Review*, 59, 1969.

"Centralization and Decentralization in Economic Processes," in Chapter 3 of *Comparison of Economic Systems: Theoretical and Methodological Approaches*, edited by A. Eckstein, University of California Press, Berkeley, 1971; reprinted in: *Jahrbuch der Wirtschaft Osteuropas*, Band 3, 1972.

*"On Informationally Decentralized Systems," in *Decision and Organization (Volume in Honor of J. Marschak)*, edited by R. Radner and B. McGuire, North-Holland Press Co., Amsterdam 1972.

"On the problem of Integrability of Demand Functions," in *Preferences, Utility, and Demand*, edited by J. S. Chipman, L. Hurwicz, M. K. Richter, and H. Sonnenschein, Harcourt Brace Jovanovich, Inc., New York, 1971.

"On the Integrability of Demand Functions," (with H. Uwaza), *Ibid.*

"Revealed Preference Without Demand Continuity Assumptions," (with M. K. Richter), *Ibid.*

*Preferences, Utility, and Demand*, edited by J. S. Chipman, L. Hurwicz, M. K. Richter, and H. Sonnenschein, Harcourt Brace Jovanovich, Inc., 1971.

*"On an Optimality Principle for Decision-Making Under Complete Ignorance," (with Kenneth J. Arrow), In *Uncertainly and Expectations in Economics*, edited by J. L. Ford and Charles Carter, Alden Press, Oxford, 1971.

"Organizational Structures for Joint Decisions Making: A Designer's Point of View," in *Interorganizational Decision Making*, edited by Matthew Tuite, Roger Chilsholm, and Michael Radnor, Aldine Publishing Co., Chicago, 1972.

*Patents, Invention, and Economic Change*, by Jacob Schmookler, edited by Zvi Griliches and L. Hurwicz, Harvard University Press, Cambridge MA, 1972.

"On the Boundedness of the Feasible Set Without Convexity Assumptions," (with Stanley Reiter), *International Economic Review*, 14 (3), October 1973.

*"The Design of Mechanisms for Resource Allocation," *American Economic Review*, 58(2), May 1973; also in: *Frontiers of Quantitative Economics*, edited by M. D. Intriligator, and D. A. Kendrick, North-Holland, Amsterdam, 1974.

"A Stochastic Decentralized Resource Allocation Process," (with Roy Radner and Stanley Reiter), *Econometrica*, 43, 1975; Part I published in No. 2, March 1975: Part II published in No. 3, May 1975.

*Studies in Resource Allocation Processes*, edited by K.J. Arrow and L. Hurwicz, Cambridge University Press, 1977.

"On the Dimensional Requirements of Informationally Decentralized Pareto-Satisfactory Processes," in Studies in Resource Allocation Processes, edited by K. J. Arrow and L. Hurwicz, Cambridge University Press, 1977.

"Convexity of Asymptomatic Average Production Possibility Sets,"(with Hirofumi Uwaza), *Ibid.*

"On the Stability of Competitive Equilibrium II: a Postscript," (With Kenneth J. Arrow), *Ibid.*

"Construction of Outcome Functions Guaranteeing Existence and Pareto Optimality of Nash Equilibria," (with David Schmeidler), *Econometrica*, 46 (6), November 1978.

"Incentive Structures Maximizing Residual Gain Under Incomplete Information," (with Leonard Shapiro), *The Bell Journal of Economics*, 9 (1), Spring 1978.

"On Informational Requirements for Non-Waseful Resource Allocation Systems," *Mathematical Models in Economics: papers and Proceedings of a U.S.-U.S.S.R. Seminar, Moscow 1976*, NBER, New York, 1978; also in: *Issues in Contemporanry Microeconomics and Welfare*, edited by George Feiwel, MacMillan, London 1985.

"On the Interaction between Information and Incentives in Organizations," in *Communication and Control in Society*, edited by K. Krippendorf and K. Gordon, Breach Science Publishers, Inc., New York, 1979.

"Ville Axioms and Consumer Theory," (with M. K. Richter), Center for Economic Research, University of Minnesota, Disc. Paper No. 76-76, September 1976; *Econometrica*, 47 (3), May 1979.

"An Integrability Condition, with Application to Utility Theory and Thermodynamics," (with M. K. Richter), Center for Economic Research, University of Minnesota, Disc. Paper No. 76-75, (revised February 1977); *Journal of Mathematical Economics*, 6 (1979).

"On Allocations Attainable Through Nash Equilibria," *Journal of Economic Theory*, 21 (1), 1979; also in *Aggregation and Revelation of Preferences*, Chapter 22, edited by J.-J. Laffont, North-Holland, 1979.

"Outcome Functions Yielding Walrasian and Lindahl Allocations at Nash Equilibrium Points," *Review of Economic Studies*, 46 (2), 1979.

"Socialism and Incentives: Developping a Framework," *Journal of Comparative Economics*, 3, 1979.

"Balanced Outcome Functions Yielding Walrasian and Lindahl Allocations at Nash Equilibrium Points for Two or More Agents," in *General Equilibrium, Growth, and Trade, Essays in Honor of Lionel Mckenzie*, edited by J. Green and J. Scheikman, Academic Press, 1979.

"Discussion," in *Models of Monetary Economics*, edited by Neil Wallace and John Kareken, Federal Reserve Bank of Minneapolis, MN, 1980.

"On Incentive Problems in the Design of Non-Wasteful Resource Allocation Systems," in *Studies in Economic Theory and Practice Essays in Honor of Edward Lipinski*, edited by J. Los, North-Holland, 1981; a longer, preliminary version in: *2nd U.S.-U.S.S.R. Symposium on Econometric Modeling*, May 23-26, 1978, U.S.-U.S.S.R. Exchange Program in Science and Technology Application of Computers to Management, College Parck, MD, 1980.

"Perspectives in Economics," *Economic Essays in Honor of E. T. Weiler*, edited by George Horwich, and J. P. Quirk, Purdue University Press, West Lafayette, IN, 1981; also in *Perspectives on Economic Education*, Proceedings from National Conference on Needed Research and Development in Precollege Economic Education, February 12-14, 1976, edited by D. R. Wentworth, W. Lee Hansen, and Sharryl H. Hawke, SSEC (jointly with JCEE and NCSS), Boulder, CO, 1977.

"Commentary," *Knowledge and Power in a Global Society*, edited by Willian M. Evan, Sage Publications, Beverly Hills, CA, 1981.

"On the Generic Non-Optimality of Dominant-Strategy Allocation Mechanisms with an Application to Pure Exchanges Economies," (with Mark Walker), SUNY, Stony Brook Working Papers, Department of Economics, Research Paper No. 250, September 1983.

"Economic Issues in the Utilization of Knowledge," in *The Optimum Utilization of Knowledge: Making Knowledge Serve Human Betterment*, edited by Kenneth Boulding ald Lawrence Senesh, Westview Press, Boulder, CO, 1983; reprinted in: *Dimensions of Rural Development in India-T.K. Lakshman Commemoration Volume*, edited by B. K. Narayan, Himalaya Publishing House, Bombay and New Delhi, March 1987.

"Discrete Allocation Mechanisms Part I: Designing Informationally Efficient Mechanisms when Desired Outcomes are Bounded," (with Thomas Marschak), Working Papers in Economic Theory and Econometrics, IP-322, Center for Research in Management Science, Institute of Business and Economic Research, University of California, Berkeley, May 1984.

"On the Stability of the Tâtonnement Approach to Competitive Equilibrium," in *Abstracts for the Workshop on Price Adjustment, Quantity Adjustment, and Business Cycles*, Institute for Mathematics and its Applications Preprint #59, University of Minnesota, February 1984 and *Lecture Notes in Economics and Mathematical Systems #264 Models of Economic Dynamics*, edited by Hugo F. Sonnenschein, Springer-Verlag, New York, 1986.

"'Economic Planning and the Knowledge Problem: A Comment," *The Cato journal*, 4, Fall 1984.

"Incentive Aspects of Decentralization," in *The Handbook of Mathematical Economics* 3, edited by Kenneth J. Arrow and Michael Intriligator, North-Holland, 1985.

"On Sensitivity and Decentralization in Infinite Horizon Models," (with Mukul Majumdar), Department of Economics, Cornell University Working Paper 368, revised November 1985.

"A Perspective," in *Social Goals and Social Organization: A Volume in Memory of Elisha Pazner*, edited by L. Hurwicz, David Schmeidler,, and Hugo Sonnenschein, Cambridge University Press, 1985.

"Discrete Allocation Mechanisms: Dimensional Requirements for Resource-Allocation Mechanisms When Desired Outcomes are Unbounded," (with T. Marschak), *Journal of Complexity*, Vol. 1, 1985.

"On Informational Decentralization and Efficiency in Resource Allocation Mechanisms," in *Studies in Mathematical Economics*, edited by Stanley Reiter, The Mathematical Association Preprint #22, University of Minnesota, Minneapolis, February 1986.

"On the Implementation of Social Choice Rules in Irrational Societies," in *Social Choice and Public Decision Making: Essays in Honor of Kenneth Arrow*, Vol. 1, edited by Walter Heller, Ross Starr, and David Starrett, Cambridge University Press, New York, 1986.

"Inventing New Institutions: The Design Perspective," *American Journal of Agricultural Economics*, May 1987.

"On the Demand Generated by a Smooth and Concavifiable Preference Ordering," (with James Jordan and Yakar Kannai), *Journal of Mathematical Economics*, 16 (2), 1987.

"T.C. Koopmans' Contribution to Economics," in *The New Palgrave: A Dictionary of Economic Theory and Doctrine*, edited by john Eatwell, Murray Milgate, and Peter Newman, Stockton Press, 1987.

"Approximating a Function by Choosing a Covering of Its Domain and $k$ Points From Its Range," (with Thomas Marschak), *Journal of Complexity*, 4 (2), 1988.

"On the Generic Non-Optimality of Dominant-Strategy Allocations Mechanisms: A General Theorem that includes Pure Exchange Economies,'" (with Mark Walker), SUNY, Stony Brook Working Papers, Department of Economics, Research Paper No. 310, July 1988.

"Optimal Intertemporal Allocation Mechanisms and Decentralization of Decisions," (with Mukul Majumdar), *Journal of Economic Theory*, 45 (2), August 1988 and Department of Economics, Cornell University Working Paper 369, revised November 1985.

"On Modeling Institutions," presented at the American Economic Association Meetings in New York, December 1988. "Effects of Entry on Profits under Monopolistic Competition," in *The Economics of Imperfect Competition and Emplyment: Joan Robinson and Beyond*, edited by George R. Feiwel, New York University Press, New York, 1989.

## Publications in Press or Accepted for Publication

"Iterative Plannig Procedues with a Finite Memory," (with William Thompson) in *Theoretical Foundations of Development Plannig*, edited by S. Bhagwan Dahiya, Jan Tinbenger Educational Foundation Trust, India, forthcoming chapter on game theoretic aspects of the implementation problem for the *Handbook of Game Theory with Economic Applications*, being edited by Robert J. Aumann and Sergiu Hart.

"On a Generalized Bayesian-Minimax Approach to Statistical Estimation," to appear in the Karl A. Fox Festschrift, being edited by Tej K. Kaul and Jati K. Sengupta.

"A necessary Condition for Decentralizability and an Application to Intertemporal Allocation," with Hans Weinberger. Institute for Mathematics and Its Application Preprint #340, September 1987. (Submitted for publication).

## Research in Progress

"On Constructing an Informationally Decentralized Process Implementing a Given Performance Function," (with S. Reiter and D. Saari), presented at the 1978 Decentralization Conference.

"Feasible Implementaiton of Social Choice Correspondences by Nash Equilibria," (with E. Maskin and H. Postlewaite), presented at IMSSS summer symposium in 1979.

"Impossibility of Smooth Nash Implementation of a Pareto-Optimal Correspondence in an Economy with Two Agents," with Hans Weinberger.

"Mechanisms and Institutions," presented at the International Economic Association Tokyo Round Table Conference, September 1987.

* NOTE: Asteriscs indicate papers that have been repinted in *Studies in Resource Allocation Processes*, edited by K. Arrow and L. Hurwicz, Cambridge University Press, 1977.

EXCLÒS DEL PRÉSTEC


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