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by

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MODELING THE EXPERIMENTALLY ORGANIZED ECONOMY
– Complex Dynamics in an Empirical Micro–Macro Model of Endogenous Economic Growth [1]

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The Swedish micro-to-macro model, MOSES, is used to show how complex economic behavior emerges from interacting, boundedly rational agents. The simulation model has been calibrated using business firm data. Nonlinearities arise in its specification of technology, the distribution of firm characteristics and in the rules that govern entry and exit. The model economy is characterized by a restless competitive growth process that is normally robust, but that now and then generates phases of local disorderly behavior including – for some parameter settings – the collapse of entire sectors.

The model explains why Government agents have difficulty predicting the reactions of the economy to policies, suggesting that Government treads cautiously in order not to do more harm than good.

1 Modeling the Experimentally Organized Economy

The experimentally organized economy derives its dynamic properties from the fact that there is an infinite number of ways by which factors of production can be combined, within a factory, within a firm, within a sector and among the firms of a whole economy.[2] Since all agents will want to stay

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[1] This paper has benefited from many constructive comments from Gérard Ballot, Bo Carlsson, Richard H. Day, Stefan Fölster, Thomas Lindh, Sten Nyberg and Pavel Pelikan. I am particularly grateful for the critical comments and suggestions for improvements of Erol Taymaz, who also designed and carried out the simulation experiments.

[2] A conventional economic model makes (1) this *opportunity set* [often called *state space* or *commodity space* (see Eliasson 1990b)], or the set of all inputs and outputs convex and sufficiently small to be fully transparent, thereby (2) eliminating restricted vision ("boundedly rational behavior") of its agents as well as the presence of "tacit" non–tradable knowledge, ensuring a state of information as perfect as needed for all agents to find themselves in a unique (equilibrium) position, because the transactions costs associated with "getting into equilibrium" are nil. They have to be (Day 1991) since otherwise the equilibrium position would change, as soon as agents had located themselves in equilibrium, thereby no longer using the resources needed to find it, thereby changing the equilibrium position.

there, there is no economic behavior in the classical model. Ex ante plans always equal ex post realizations. Some combinations are better than other combinations. There are probably many equally good combinations that have not yet been discovered. To improve given combinations experiments are needed, and no one knows the best until all possible solutions have been tried.

Management of a factory or the management of a firm faces this dilemma of restricted vision. The finer the detail, the larger the number of combinations (process solutions) within that technology that can be captured with the measurement system. If *sufficiently fine there will always be – at given relative prices – a different combination that yields a higher aggregate productivity or a higher profitability.* Furthermore, *each shift in relative prices means that a new combination will give at all levels of aggregation the best economic performance.* The Swedish Micro–to–Macro model – to be used in this analysis –sets up such an allocation game between firms, and the game generates a macro outcome through competition in markets.

Competition in an experimentally organized market environment, however, has nothing to do with competitive equilibrium. Rather competition is original Adam Smith (1776) competition, involving rivalry and innovative entry.[3] This creates a constant state of disequilibrium in the capital market, generates macroeconomic growth and creates systematic divergencies between ex ante plans and ex post realizations. What we have here is a synthesis of Schumpeterian and Wicksellian ideas in the spirit of the Stockholm School of Wicksell, Myrdal 1927, Lindahl, Svennilson, Lundberg etc. (See Palander 1941 and Eliasson 1968).

This paper presents a quantitative model of the experimentally organized economy in which mistaken plans are part of the costs of macroeconomic growth, where selection mechanisms introduce non-linear and path-dependent trajectories, that exhibit now and then unpredictable, disorderly behavior. The source of unpredictability lies in the path-dependence and non-

[3] Anderson, G.M. and Tollison, R.D. (1982), show that the competitive model is a false representation of the invisible hand of Adam Smith, who emphasized rivalry and competitive entry as the critical elements of the competitive coordination process.

stationarity of the realization process, preventing unbiased learning of agents, hence removing the possibility of full information, or a perfect market equilibrium, the cornerstone of the static general equilibrium model. The reason for this is "bounded rationality" or restricted vision on the part of agents.

I will use the Swedish micro-to-macro model as a "reference reality" to discuss the possibility agents have to decode its design, using external data generated by the model and statistical learning techniques. A critical element of my argument is that the policy authority in the non-learnable environment of the experimentally organized economy has no information advantage over any other agent. The situation is rather the reverse. The policy authority is a monopolist that significantly influences the behavior of the system when interacting with it, thus making it still more difficult to predict the consequences of policies. The policy authority, hence, has to tread very cautiously in order not to do more harm than good.

Section 2 gives a brief overview of the main features of MOSES. Section 3 summarizes general characteristics of the model structure. Section 4 presents several sample simulations. The paper concludes with some reflections inspired by the analysis on the role of government in the economy.

2 The Swedish Micro-Macro Model

The MOSES model was originally designed for analyzing industrial growth. Therefore, the manufacturing sector is the most detailed sector in the model. Manufacturing is divided into four industries or markets (raw materials, processing, semi–manufacturers, durable goods manufacturing, and the manufacture of consumer nondurables). Each industry consists of a number of firms, some of which are based on actual industrial business records, and some of which are synthetic. Together, the synthetic firms in each industry make up the differences between the "real" firms and the industry totals in the national accounts. 225 firms inhabit the manufacturing sector, 154 of which are real firms, or divisions in the base year, currently 1982. The model is

based on a *quarterly* time specification. For full technical detail see Eliasson (1977, 1985), Bergholm (1989) and Albrecht et al. (1989).

–My purpose with the initial design of MOSES was to incorporate, in a mathematical model some essential elements of business decision making derived from my detailed studies of firm behavior and organization (Eliasson 1976, 1984b). The ones most essential for understanding the overall character of the model are briefly described

2.1 The Nature of the Firm

In the real world firms peek into a for all practical purposes infinite *opportunity set.* Their vision is restricted by their *local competence to understand* what is going on around them. Competition pushes agents into a restless experimental search into the opportunity set. This is the source of macroeconomic growth. To understand macroeconomic growth you have to understand the learning and competence upgrading techniques of firms that accrue as a result of the process.

Firms seek profit by a hill climbing search guided by perceived profit opportunities. But the *landscape of immediate profit opportunities constantly changes as a consequence of all agent behavior.* Ex ante plans, hence, normally fail to match the constraints imposed by the plans of all other actors and the characteristics of the environment of opportunities. Unpredictability rules at the micro level and individual mistakes are frequent. Firms, as a consequence, are organized to experiment and they specialize in fast identification and effective correction of business mistakes. The ability to do so i*s* what I mean by "economic competence" (Eliasson 1990b).

Failure of agent plans shows up in unused capacity, undesired stocks and price adjustment. Constant failure of ex ante plans to match at the micro level, causes a constant ex ante/ex post dichotomy at all aggregation levels. Such mistakes are part of the costs incurred at the micro level to achieve economic growth at the macro level. As suggested in Eliasson (1983, 1984a) minimizing such costs in the short run through stabilization policies may

create even larger adjustment costs in the longer run, and may reduce macroeconomic growth.

To tell how prices and quantities will move out of equilibrium you need a process representation of economic activity in which learning behavior and expectations forming, decision making and the realization processes are explicit in time. The nature of the *plan realization process*[4] determines the state of information in the economy, the potential for learning reliably about its fundamentals and the feasibility of a state of full information. The complexity of such a model, however, even though being much less complex than reality, prevents the outsider economist from predicting the macro behavior of the model, having access only to the data generated by the model. The outsider, hence, is in the same position as the agent (firm) of the model trying to understand what goes on around him.

Economic development is characterized by reorganization of micro structures through exit and entry. The evolving micro state is a *"tacit" memory of competence*, that determines the ability of the firm to exploit the opportunity set, and at each point in time bounds the feasibility of future states. Unexploited business opportunities are available through trial and error experimentation. The fact that individual firms are exposed to competition by all firms and that these price and profit expectations depend on experience are sufficient to move the entire MOSES economy.

In MOSES each firm is not in touch with all other firms individually. Instead *it interprets various items of aggregate information ("indices") generated by the market process* with a delay. The nature and efficiency of this learning process depends on markets and hierarchies, but learning also affects the market organization and hence the future efficiency of economic learning, creating a *path-dependent* evolutionary process, that cannot be predicted due

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[4] The plan realization process embodies the ideas of the Stockholm School of Economics and of Wicksell (1898), Myrdal (1927) in particular. See Palander (1941) and Eliasson (1968). The idea was later, and independently, formulated as a realization function by Modigliani, F. and Cohen, K. (1958, 1961).

to the complexity of the combinatorial organizational possibilities facing the agents of the economy.

2.2 Business Decisions: Learning about interior firm capacities

Because no firm management is fully informed about its own capacity to produce, I represent firm decisions by a boundedly rational, internal search that I call *MIP targeting* (MIP = **M**aintain or **I**mprove **P**rofits. See Eliasson 1976, pp. 236ff). It represents top management competence, to force interior information to surface to improve firm performance.

The principle rests on four facts of life in all business organizations:

(1) The difficulty for top managers to set accurate targets for the interior of the organization, close to what is the maximum feasible.

(2) The experience that if targets are set *below* what is maximum possible actual performance will be lowered to targets.

(3) The importance for target credibility and enforcement that targets be set above what is conceived to be feasible, but not unreasonably high. A 'reasonable' standard is performance above that achieved in the recent past.

(4) The general experience that a substantially higher macro performance of the firm can normally be obtained if a good reason for the extra effort needed can be presented ('crisis situation') or if a different, organizational solution is chosen ('other firms do it better'), if time to adjust is allowed for.

MIP-targeting assumes that top management knows that the firm always operates somewhere below the feasible level of capacity. Past experience determines the level from which top management knows that an upward improvement in its profit rate can be achieved. The psychology of targeting is that top management knows that some improvements can be achieved.

However, knowing that excessive, impossible targets are never taken seriously even if slack is quite large, it is ineffective to impose grossly infeasible targets. Hence, targeting is organized only to push for gradual improvements. *Targeting, then becomes a form of learning* or of transferring knowledge of potential capacities within the firm organization to the top executive level. Top corporate management is probing for the limits of capacity, information that lower level management wants to conceal. If new technology is not being created, such targeting will eventually push activity onto the feasibility (production) frontier.

2.3 MIP Targeting in MOSES

Now I will briefly describe the MOSES representation of this conception of the business firm.

Defining the rate of return

Total costs (TC) of a business firm, over a one year planning horizon are defined by

$$TC = wL + (r + \rho - \frac{\Delta p^k}{p^k})p^k \cdot \overline{K} \qquad (1)$$

w = wage cost per unit of L
L = units of labor input
r = interest rate
ρ = depreciation factor on $K = p^k \cdot \overline{K}$
p^k = capital of goods price, market or cost
$\overline{K}$ = units of capital installed

The various factors $(L,\overline{K})$ *within* a firm can be combined differently, and still achieve the same total output. Depending upon the nature of this allocation the firm experiences higher or lower capital and labor productivity.

Firm sales ($S=p^* \cdot \bar{S}$) over total costs generate surplus revenue, ε, or profit:

$$\varepsilon = p^* \cdot \bar{S} - TC \tag{2}$$

Net profit per unit of total capital R^N is the rate of return on capital in excess of the loan rate:

$$\hat{\varepsilon} = \varepsilon / K = R^N - r \tag{3}$$

$$R^N = \frac{\varepsilon + rK}{K} \tag{3B}$$

In this formal presentation K has been valued at current reproduction costs, meaning that ε/K expresses a real excess return over the loan rate, but that r is a nominal interest rate.

In the MOSES model firm owners and top management control the firm by applying targets on R^{EN}, the return on equity, i.e. they apply profit targets in terms of ε. The present value of all future ε is the value created by firm management over and above the value these resources would have created if allocated to a reference investment yielding a rate of return equal to the interest rate (= r). Thus, we have established a direct connection between the goal (target) structure of the firm and its operating characteristics in terms of its various cost items.

The Control Function of the Firm

Using (1), (2) and (3) the fundamental control function of a MOSES firm can be derived as:

$$R^{EN} = M \cdot \alpha - \rho + \frac{\Delta p^k}{p^k} + \hat{\varepsilon} \cdot \phi = R^N + \hat{\varepsilon} \cdot \phi \tag{4}$$

$$M = 1 - \frac{w}{p^*} \cdot \frac{1}{\beta} \tag{5}$$

where:

M = the gross profit margin, i.e., value added less wage costs in percent of S

R^{EN} = $(p^*\bar{S}-TC)/E$ the nominal return to net worth (E = K–D).

ρ = rate of economic depreciation

α = $\bar{S}/K$

β = $\bar{S}/L$

ϕ = Debt/E = K–E/E

ε = $(R^N-r)K$

D = Nominal Debt

Management of the firm *delegates responsibility* for, and authority over the operating departments through (4) and appropriate short-term targets on M (production control) through (5). Long-term targets on ε control the investment decision.

$\hat{\varepsilon}\cdot\phi$ defines the contribution to overall firm profit performance from the financing department.

A target on M means a labor productivity target on $\bar{S}/L$, conditional on a set expectations on (w,p*) in (4) determined through individual firm adaptive error learning functions (see below). Thus, the profit margin can be viewed as a price-weighted, "inverted" labor productivity measure.

Long–term objective function (investment selection)

The objective function guiding long-term investment behavior is to select investment projects that satisfy (ex ante):

$$\varepsilon/K = R_i^N - r_i > 0$$

where R_i^N is the local rate of return of the firm. The local loan rate r_i depends on the firm's financial risk exposure, measured by its debt-equity position.

$$r_i = F(r,\phi),\ \frac{\partial F}{\partial \phi} > 0 \tag{6}$$

The expected $\hat{\varepsilon}$ drives the rate of investment spending of the individual firm. The standard notion of a Wicksellian capital market equilibrium is that of "average" $\hat{\varepsilon}= 0$ across the market. As a rule this state is not achieved. Unused capacity may prevent the firm from investing in new capacity even though investment long term is expected to yield $\hat{\varepsilon} > 0$. More important, however, is the fact that realized investment comes later than the current quarter and that firms continue to make mistakes.

Production capacity structure of firm (state description)

Production planning is carried out individually by each firm. Each firm chooses a preliminary, planned output and labor combination (Q,L) from a set of feasible combinations each quarter that are delimited by

$$QFR = QTOP^* \left[1-\exp(-\gamma \cdot L)\right] \tag{7}$$

This feasible set (for a graphic illustration see Figure 2 in Eliasson 1977) is determined by the firm's past investments. Investment between quarters pushes this set outward.

The *satisfactory* (Q,L) combinations are those that give output levels at least is big as [see equations (5) and (9)];

$$\frac{Q}{L} \geq \frac{EXP(w)}{EXP(p^x)} \cdot \frac{1}{1 - TARG(M)} \tag{8}$$

where TARG(M) is the quarterly profit margin target (see Eliasson 1977). The shaded area in Figure 1 defines the feasible and satisfactory production set.

Insert Figure 1 about here!

Targeting is done on a yearly basis with quarterly adjustments. Profit margin targets are adapted gradually as new information on what is possible to achieve is accumulated. Bad profit experience can make the firm lower its target in the short term. This will normally affect long-term development negatively; immediately through smaller cash flows and in the longer term through less investment and perhaps also less profitable investment, that lowers future cash flows.

2.4 Learning for coordination

Each MOSES firm forms a provisional production and investment plan on the basis of expectations on its product prices, its sales and its wages, all being constrained by its profit targets, reflecting the rate of return requirements imposed by the capital market. These rate of return requirements in turn depend on the market interest rate which is determined by the supply and demand for funds in the capital market.

Expectations functions

To project price, sales and wage expectations (X) the MOSES firm employs adaptive error correction learning or expectations functions of the type:

Internal:
$$\mathrm{EXPI(X)} = \mathrm{HIST(X)} + a\mathrm{HIST(ERROR\ EXP)} + \beta\sqrt{\mathrm{VAR\ ERROR}} \tag{9A}$$

External:
$$\mathrm{EXPX(X)} = \mathrm{Exogenous}$$
$$\mathrm{EXP(X)} = (1-\mathrm{R})\ \mathrm{EXPI(X)} + \mathrm{R}^*\mathrm{EXPX(X)}, \tag{9B}$$
$$0 \leq \mathrm{R} \leq 1$$

The expected value of X is projected through a smoothing formula from past observations, a linear error correction of past errors and a variance measure reflecting the aversion to risks of the agent. This formula is

$$\text{HIST}(X) := \lambda_1 \text{HIST}(X) + (1-\lambda_1) X \qquad (9C)$$

$$\text{HIST}(\text{ERROR}) := \lambda_2 \text{HIST}(\text{ERROR}) + (1-\lambda_2) \text{ERROR}$$

$$\text{HIST}(\text{ERROR}^2) := \lambda_3 \text{HIST}(\text{ERROR}^2) + (1-\lambda_3) \text{ERROR}^2$$

$0 \leq \lambda_2 \leq 1$

Note the algol notation := which means, make equal to.

Selecting the production plan

On the basis of its (p^x,w,S) expectations the firm now chooses a point in Figure 1 that is ex ante both feasible and satisfactory. This is done by specifying an initial set of (Q,L) points and the rules to adjust these points if they do not fall within the feasible and satisfactory lens area. Labor productivity is adjusted, reflecting the fact that the market price and quantity decisions have already been taken. Product market decisions are revised from quarter to quarter. (This is discussed in Eliasson 1985, Albrecht, J. et al. 1989.)

Inventories exist as buffers on the input and the output sides. Each firm aims for a desired level of inventory as a percent of production, but always comes out ex post with too much or too little depending on how production plans are realized. Each production planning round aims at restoring desired inventory levels.

The realization function defined

The "invisible hand" of Adam Smith will not always succeed in directing firms, guided by the profit motive to draw up plans that all match such that markets are cleared. Mismatches and unrealistic plans are the normal situation, and a situation of rest where all plans come true, static equilibrium may not even exist (see below). The nature of ex ante, ex post departures are

summed up in the realization function, especially the micro realization of ex ante returns over the interest ($=\hat{\epsilon}$).

The exact composition of ex ante and ex post $\hat{\epsilon}$ differences is shown mathematically by computing $\hat{\epsilon}$ in (3), first using expected (p^x,w,S) using (9A,B,C) then again using realized (p^x,w,S), and taking the difference. Weighted distributions over firms, using total capital as weights, are shown in figures 4A,B. The evolution of $\hat{\epsilon}$ distributions summarize all underlying real behavior including decisions on pricing, to enter and exit etc. A dynamically well coordinated market economy should exhibit a long term development of $\hat{\epsilon}$ distributions approaching averages around 0, but maintaining from year to year significant diversity (see Eliasson 1984a). The erratic behavior will be reflected in the length and scope of departures of average $\hat{\epsilon}$ from zero.

2.5 The Salter Curve of Operating Characteristics and Innovative Entry

Firms in the model are represented by a distribution of potential performance characteristics, like the rates of return over the interest rate in Figure 2A. Such distributions – especially if presented as productivity rankings of establishments (Figure 2B) – are often referred to as Salter (1960) curves. Each firm is represented on this curve by a ranking on the vertical axis, the width of the column measuring the size of the firm in percent of all other firms. (Figure 2A shows that even though the firm indicated has increased its rate of return between 1982 and 1992 it has lost in ranking. Figure 2B shows the same firm's labor productivity positions.)

Each firm also has its own potential productivity frontier, under which it is operating to position itself on the productivity and rate of return rankings. This is still actual ex post performance. The dynamics of markets on the other hand is controlled by a second set of *potential ex ante* distributions, that capture the planned actions of all other firms, including new entry.

There is a third set of Salter curves that tell how *each firm sees itself positioned relative to other firms.* The real world of the experimentally organized economy, and its model approximation, the Swedish micro-to-

macro model shows large *divergencies between actual and perceived positions.* These ex ante distributions indicate the potential for a given firm to outbid all other firms in wages, or in paying a higher interest rate.

The firm learns directly if competitors can do better. Management then knows that it had better improve in order not to be pushed down along the Salter distribution, and, perhaps, out. Similarly, when the firm finds itself close to the top, it knows that close competitors are taking actions to better their positions through innovation or imitation. If potential Salter distributions are sufficiently steep in the top left-hand group, firms attempt to improve their positions on the Salter curve through innovative activity, or through entry. This moves the entire economy through a selfperpetuated competitive process.

2.6 Competition through Entry and Exit

The Salter curves of each market are constantly upgraded through competitive exit ("creative destruction") and entry. Only firms which have acquired superior performance characteristics through learning in markets and through interior process efficiency survive in the long run.

New firms enter the market as new investment vintages in response to opportunities in the market represented by excess returns to capital $\hat{\varepsilon}$ generated there (see Hanson 1986, Eliasson 1991). The size and performance characteristics of each new entrant is a drawing from a distribution of these characteristics.

Firms exit when they constantly fail to meet profit targets and/or when net worth is exhausted, declaring their assets to be of nil value and laying off all labor. Laid-off labor is then available for work through the pool of unemployed. Machine capital is scrapped.

2.7 The Creation and Introduction of New Technology

A new investment vintage can be regarded as a "new firm" with exogenous potential *capital productivity* (α=S/K) [see equations (4) and (5)] and *labor productivity* (β=S/L) *characteristics.* S is output volume, K and L are capital and labor input respectively. A new investment can be seen as a new vintage of capital with these particular technology (α, β) characteristics that mix with capital installations in existing firms. Technology is embodied in new investment vintages. Hence, business opportunities are represented by current (α, β) specifications of new investment vintages, while *local receiver competence* is defined by the local investment process (and – of course – the short-term production decision) that upgrades the technical specifications (the "frontier") of the firm, under which quarterly production decisions are taken.

The productivity upgrading process takes place in four steps (see Eliasson 1985, pp. 329 f.). Call current operating productivity of one unit of measurement, one firm (α, β), when operating on the QFR(L) frontier (α^*,β^*), and productivity associated with new investment (α^{**},β^{**}).

(1) Actual, operating labor and capital productivities (α, β) are pushed by competition towards *potential* productivity (α^*, β^*) on the frontiers. *Static operating efficiency* of the economy improves (see Figure 2B).

(2) Potential productivity (α^*, β^*) of existing units is increased through more investment of higher productivity [investment of quality (α^{**}, B**) > (α^*, β^*) raises $\longrightarrow$ ($\Delta\alpha^*$, $\Delta\beta^*$) of existing units]. *Neoclassical efficiency* improves.

(3) Reorganizations between existing firms raise (α^*, β^*) at higher levels of aggregation. Labor is reallocated towards the more efficient plants. *Allocational efficiency* improves.

(3B) When all three changes above occur simultaneously *dynamic allocational efficiency* improves.

(4) *Innovations* create new type ($\Delta\alpha^{**}$, $\Delta\beta^{**}$) of productivity characteristics. *Schumpeterian efficiency* is improved as these new investments enter the economy through the intermediation of entrepreneurs, and competes old technology out of business (creative destruction), thus upgrading the Salter structures of the economy.

3 General Model Characteristics

Explicit aggregation to macro through markets

Productivity change appears as changes in the organizational structure or memory of the M-M model, embodying in turn the *informational technology* of the economy. Even though there are technical capacities that allow a productivity performance way above current standards, the economy is always operating well below what is possible if best-practice equipment and competence were diffused throughout the economy. Information and social adjustment costs prevent the economy from operating on "its" best-practice trajectory, and innovations keep the potential ahead of applications (Carlsson 1984, 1987, Carlsson–Taymaz 1991).

This means that the rules controlling the dynamics of market interaction among agents will influence measured productivity performance, not only strongly but also in highly non-linear ways. The Salter landscape over which ex ante prices guide quantities is extremely complicated, and will cause such dynamics of ex post price determination that the ex ante price feedback can generate highly erratic behavior of agents for extended periods of time (see e.g. Eliasson 1978, pp. 118ff, 1983, 1984a). For instance, firms guided by the way they interpret market signals will operate during periods and between periods underneath the production frontiers, or along them, while production frontiers change from period to period through endogenous investment. Simultaneously competition in markets changes because of this ongoing interaction, entry and exit. For instance, it will be common that capacity

utilization (of labor and machinery) increases as production increases in the early upswing, raising productivity and lowering costs.

Profits and productivity

Very simply expressed, the M-M model economy consists, *first*, of a set of *potential* and *actual* Salter (1960) curves making up the *initial state description of its capacity and competence structure. Second*, each agent is characterized by its *learning, targeting and realization behavior.* Behavior, and the initial state description of all agents together define the economy's short-term state space. Third, each agent is characterized by its ability to *accumulate capacity and competence* in the right market to earn a return on its capital, through investment and selection, all being controlled by the short-term market realization process. The Salter curves keep changing through the ongoing process of technological competition, through exit and entry, through investment, bringing in new best-practice methods, through innovation, improving best-practice methods and through efficient, short-term market performance, reducing slack, and the difference between actual and potential Salter distributions. The efficiency of competition, furthermore, is dependent on the state of new, best-practice technology, the slope of the Salter curves and other factors characterizing the speed of market processes.

Search is guided by a comparison of the productivity ratio to an equally scaled expected price ratio. The initial positioning of L and a corresponding expected sales volume establish an initial activity level of production. The search path into the shaded lens in Figure 1 may, however, lead onto B, and down along it, to a premature collapse of operations. This may be incompatible with rational behavior in the sense that the firm deliberately chooses to lower its expected profits to find a quarterly (Q/L) combination within the shaded area. To prevent this a supplementary rule stops further search whenever expected profits begin to decrease.

For each L, there is an interval of output plans that are (1) either both feasible and satisfactory in the shaded lens (Region A) in Figure 1 (computed

for a real firm in the model 1983), and/or (2) feasible but not satisfactory (Region D), or (3) neither feasible nor satisfactory (Region C).

The state of slack across firms – the vertical distance to QFR in Figure 1A – is measured every year in the Planning Survey of the IUI and the Federation of Swedish Industries on which the model is empirically based. Each year some firms are operating at full capacity, but most are not. We also know roughly from empirical studies (see for instance Eliasson 1976) *how* firms adjust their output plans in a stepwise fashion. Production search in the model has been tailored to mimic such procedures within firms. When a model run is set up, the state of slack is assessed for the initial year in the initialization process (see Albrecht and Lindberg 1989). The state of slack is then monitored through the MIP-targeting and production planning procedure every quarter by every firm as the simulation goes on. When a feasible and satisfactory (Q,L) point in Figure 1 is reached, the firm's preliminary plan is set at the minimum Q such that SAT(Q,L) holds. If SAT(Q,L) does not hold, and if the point is in region A, the firm adjusts by planning to lay off labor. If this does not help, the firm's preliminary plan is to set the minimum feasible Q and L. Each firm now has a planned employment and output level. At the aggregate level, however, these plans may not be feasible. Firms must confront one another in the labor and product markets to sort out remaining inconsistencies.

It is of interest to note that this search for improved ex ante profit positions is guided by partly biased price and quantity signaling in markets. There are costs associated with this search in the form of mistaken decisions. The previous experiments illustrate that such costs increase the closer the economy comes to "static equilibrium" because of increasing unreliability of price signals. This means that the economy has to operate constantly underneath its production possibility frontier, or more exactly that some firms have to operate underneath their frontiers.

For the neoclassical economist who assumes its production units to be on the frontier this is disturbing. It means for instance that machine or labor slack will be a normal operating characteristic and that firms may experience strong productivity increases (and unit/cost reductions) as output expands in

the early upswing. This seemingly contradicts the neoclassical proposition of diminishing returns. It of course does not, since diminishing returns set in when the firm comes closer to, and moves along the production frontier. Carlsson, Eliasson and Taymaz (1990) show that this is a current phenomenon both in MOSES and in reality.

4 Simulation Analysis

The above theoretical analysis only tells the results in principle. A model based on the assumptions of the experimentally organized economy will be path-dependent and exhibit periods of local, or more general disorderly behavior. The market economy of the M-M model is strongly self-regulating through price and quantity feedback. The speed of these self-correcting market mechanisms may create destabilizing systems behavior under certain conditions, but exhibits robust behavior under normal circumstances, as a realistic model of a national economy should do. Even though disruptive behavior might occur now and then, endogenous mechanisms will soon correct them.

Experiments that *can* lead to complete systems collapse can be set up under special circumstances by forcing firms in the model to behave in a more "neoclassical" way. For that purpose I set up three different experiments (Eliasson 1983, 1984).[5]

(1) BASE: A reference experiment calibrated on Swedish data for a historic period (see Taymaz 1991a,b).

(2) EQU 1 Same experiment with one (partial) "equilibrium condition" and faster market arbitrage imposed.

[5] Erol Taymaz has been very helpful in setting up and carrying out these experiments. See Taymaz (1991b).

a) Market arbitrage is – in addition to BASE – speeded up.

b) Firms strive to hold no final goods inventories.

(3) EQU 2 Same experiment as EQU 1 but with additional constraints on expectations.

c) Price, sales and wage expectations of individual agents equal sector averages.

In interpreting the simulation results it should be recalled that the differences between the experiments to be presented only have to do with the coordination and information diffusion (learning) machinery of agents in markets. The technology assumptions of the opportunity set are identical in all experiments. The no-inventories constraint is a true equilibrium condition. The "follow John" assumption that individual expectations equal average expectations is also an equilibrium condition, but in a dynamic model it can be inconsistent in the sense that it cannot be realized.

First of all, the base case exhibits a stable and considerably faster rate of growth in manufacturing output than all the other experiments (Figure 3A). The closer the model economy is moved to an equilibrium situation the slower growth in output, generating (in the fast market experiment with exactly coordinated expectations) collapse like behavior at the macro level.

The reason for the inferior macro performance of the experiments mimicking approximate static efficiency, is *bad coordination through increasingly unreliable market price signalling* (see e.g. Figures 3B,C,D). This is also reflected in jumpy investment and output growth. Even though rate of return performance is generally higher in the badly performing experiments, leading to significant underutilization of capacity, and significantly higher failure rates (exits and overly optimistic entry), long-run average growth is lowered (Figure 3E). Note that the lowering of ε after year 2000, that apparently did

not reduce investment spending, depends on an increase in all experiments in the interest rate (Figure 3F).

The collapse after some 25 years is caused by the additional expectational constraint. Firms are forced to have the same expectations as the sector average, and competition ensures that there are narrow limits between productivity performance and profit margin targets. The same thing happened in a similar experiment suggested by Gérard Ballot, where all firms were made to follow the advice of the "leader" of each market, in this case the largest firm. If the entire group of firms in one sector happens to come into a position where the average firm would go bankrupt and/or choose to exit, all firms make identical decisions. This "follow John expectational design" hence removes the robustness of the economy guaranteed by the diversity of structure (Eliasson 1984a). The collapse is sufficiently large to show at the macro level, even though it mainly occurs locally through the elimination of all firms in one sector. It occurs very suddenly in the year 2012 in experiment EQU 2 but not in the other experiments (see Figures 3G,H,J). In all experiments there is a steady exit of firms from the initial state. While the number of firms is maintained (through entry) in the BASE and EQU 1 cases the population of firms drops dramatically in the EQU 2 experiment at the time of macro collapse. This is apparently an irreversible structural change, that establishes path dependence.

The collapse itself is impossible to predict on the basis of signals emitted from the ongoing economy. The signals in fact look very similar in the EQU 1 and 2 experiments, but only one leads to economic break-down. However, in both cases the observer can see that something is fundamentally wrong with the economy compared to the BASE case. The economy is shaking like an overheated car engine, and variables like investment and rates of return are jerking back and forth.

These unstable conditions are nicely illustrated in the realization functions. The distributions of ex ante/ex post $\hat{\varepsilon}$ normally fluctuate around a zero average in a cyclical fashion as the economy is behaving nicely, i.e. in the BASE case, only to completely change character for many years around the collapse incident in EQU 2. The EQU 2 experiment exhibits very irregular $\hat{\varepsilon}$

behavior, and systematic shifts of $\hat{\varepsilon}$ distributions over the collapse period phase, shifts that cannot be predicted from the "information" (price and quantity signals) emitted previously from the ongoing economy (Figures 4).

These experiments illustrate the grand paradox of neoclassical economics. When the dynamic model is pushing, through increasingly "efficient", but also increasingly resource-using market coordination (through mistakes), competition forces the economy closer to a static equilibrium. As a consequence the coordination mechanisms (the price system) get increasingly unreliable, destabilizing quantity behavior of the economic system. The reason is that agents of the system using adaptive, error correction learning mechanisms cannot interpret environmental signals. They make mistakes or withdraw from action. These mistakes constitute the largest transactions costs of the economy.

5 Comments on the Limits of Policy Making

Chaotic systems behavior, as we have seen, can be local, occurs during particular periods or engages the entire macroeconomy (= collapse). The nature of chaos depends on exogenous initial conditions and exogenous parameter settings. At each point in time endogenous variables of the past appear as initial conditions. By setting the parameters properly a particular set of initial conditions can be made the origin of later chaos. By changing initial conditions a particular set of parameters will do the same thing.

The interesting thing from the point of view of economic policy and systems controllability, however, is that a reasonably specified economy can be made to tick along "forever" under one set of parameter specifications, only to exhibit, with a reasonable modification of these parameters, erratic behavior at some unpredictable future period. Policy makers interact with the M-M model through modifying the parameter settings. Many of these policy manipulations, occurring in reality correspond to very strong modifications of the parameter settings of the M-M economy.

For example in Sweden, new innovative entry was contained for a long period by Government policies aimed at redistributing income. These same policies appear to induce large firms to move their new investment abroad and create a latent wage cost overshooting situation. With a decreased diversity of structure and excessive wage cost expectations the Swedish economy – to draw from model experience – could be positioned for collapselike behavior in 1991 and 1992.

Who knows the system

In order to see why government policy can cause chaos let me recapitulate the key properties of the experimentally organized economy and the source of genuine unpredictability at all aggregation levels. We, the model builders, have the exact specification of initial states and the Model Code. We can generate economic behavior from this information. Outsiders, however, without the code, know no more than an individual firm, and have to interpret the signals that the system emits through their boundedly rational and differently structured expectations functions. There will be no way for them to take in all the relevant information and transform it into an unbiased forecast.

Even so you might yield one step. Perhaps you can design an outsider intelligence system to predict MOSES behavior, lacking the code and initial state data. But you know that underneath, each agent or firm performs similar, but differently structured, internal, boundedly rational decision making, the nature of which you don't know very much about. This means that the policy maker monitoring the national economy from the outside will be as "boundedly rational" in its *understanding of the economy as each individual agent and hence as prone to making mistakes.* The central policy maker, furthermore, cannot operate as a business agent and "gamble". Mistakes at that level are potentially significantly more harmful to the economy, and leave no opportunities for gainful learning. Hence, there are *definite and narrow restrictions on the extent of meaningful policy making on the part of central policy makers.*

Even though somebody might convince you that all the successes and mistakes experienced at the micro level can be captured by a stationary and learnable process, *you cannot* be convinced as a decision maker, since you know that the structure of the system that generates this behavior is changing, and changes differently as a consequence of the ongoing experimental process, exit and entry being the most apparent such mechanisms. Hence, each experiment can be seen as participating in a lottery, where each drawing will permanently divert the economy onto a particular path, influencing the odds of the next lottery, and so on. The behavior of such an economy will normally be incomprehensible to the outside observer.[6] We know from experiments on the model that different initial conditions and parameter settings generate very different evolutionary patterns (Eliasson 1983, 1984). The same outcome of this process will be represented at the agent level by the evolution of the distributions of ex ante and ex post $\hat{\varepsilon}$.

The non-linear decision and selection mechanisms of the MOSES model have already been demonstrated to move the model economy along an endogenously determined growth path. In terms of the MOSES model this process is deterministic.

There is no principal difference between an outsider policy maker and any individual agent trying to understand what is going on in the MOSES economy, except that one might *assume*, as has become tradition in economics, that the policy maker knows the model, while agents do not. What has been said above is sufficient to prove that such assumptions are false for a model of the MOSES type. The policy maker and each agent alike, are as incapable of learning the structure of the model. One might even argue that a dominant agent (a monopolist), like the policy maker might be less capable of understanding the system if he also attempts to control (*police*) the system,

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[6] The non–linear decision and selection mechanisms of the Moses model make up a deterministic process. An outsider would lack the parameter specifications needed to interprete the signals emitted by the system to learn its structure using any estimable approximation of the model. To the outsider, hence, behavior will appear now and then unpredictable. This property falls under the definition of unstable, erratic, chaotic or disordedly (Eliasson 1983) behavior (see Saari 1989). That initial state specifictions can be the origin of chaotic behavior has been demonstrated before (see Carleson 1989). Here it can be derived from heterogeneously specified agent behavior, which is a special form of initial state specification.

since in addition to understanding as a passive observer, what is going on, he also has to understand the systems responses to his own interactions. Non-linear economies like MOSES (and the real world) hence impose narrow limits on informed policy making.

6. Postscript on the behavioral foundation of unpredictable behavior

Boundedly rational behavior of agents creates selection and choice mechanisms that in turn create path–dependent organizational structures that at each point in time control all coordination processes of the economy. To clarify this and how my model departs from the neoclassical model, let med relate it to the classical finance model.

The "boundedly rational" choice mechanisms of agents are controlled by the heterogeneous, local competence of agents. Look at the probability distribution $P(x,\theta)$ which is proportional to $P(x|\theta)P(\theta)$, which is in turn conditioned by the choice of local decision model (read competence) θ. Following Zellner (1983, p. 141 f.), suppose the rational decision maker first chooses θ as a drawing from a probability distribution $P(\theta)$. θ are "boundedly rational models" that control the choice of decisions (=x). Following Bayes' (1763) decision model the total decision problem can then be defined as a drawing from a simultaneous probability distribution [= $P(x,\theta]$ of observations (decisions = x) and parameters (decisions models = θ). I may view my choice of decision model as a drawing from a distribution of "boundedly rational" models that I think I know. I can then integrate both into a simultaneous distribution of decisions and observations. Suppose, however, that the decision maker instead follows a sequence in choosing first a decision model $\theta 1$, then a decision x, from $P(x|\theta 1)$ which in turn guides the next choice of decision model $\theta 2$ from $P(\theta 1|x_1)$ and so on. The probability distributions then cannot be integrated. The decisions become drawings from a sequence of conditional probability distributions $P(x|\theta)$, conditioned by the prior imposed by choice of decision model from $P(\theta)$.

The choice of model θ is an act of innovation. It changes the parameter of the ex post realization process compared to the parameters of the ex ante

distribution, conditioned by experience from models prior to the choice of decision model, θi form $P(\theta|x(i-1)$. The sequential updating of $P(\theta|xi)$ and $P(x|\theta)$, dependent on prior decisions θ is an act of learning and will create a path–dependent experimental process, the nature of which is inaccessible by standard instruments of statistical learning. This choice process (following Hart 1942) cannot be assumed to be the "regular risk situation", of a learnable or estimable process. The choice of θ will have to rest on the "tacit knowledge" of the firm generated by ongoing organizational learning from the realization of decisions (or drawings) from $P(x|\theta)$. With a sufficiently large number of dimensions on these choice processes extreme diversity among the controlling competence memories of firms will develop. I have demonstrated already (1990b) that heterogeneous competence (bounded rationality) is necessary and sufficient to prove the existence of such a "tacit decision memory" of the agent/firm.

"Tacit knowledge" then cannot be decoded and communicated artificially by known learning technology, classical learning being one such decoding mechanism. One might however say that the ambition to decode the "tacit memory" means assuming that it can be done. This is the assumption of rational expectations or artificial intelligence approaches to management decision making. If the assumptions from learning do not hold up, however, the parameters of the ex post realization process will differ from the ex ante decision process, and the realization function will exhibit systematic errors that cannot be decoded and corrected. Rational expectations models are designed a priori to make decoding feasible. New results on so–called "neural networks" (Day 1975a, Crick 1989, Maddox 1989), however, have demonstrated mathematically how complex systems with synaptic interconnections develop controlling memories that cannot be decoded from external observation. The output of these memories allows the external observers neither to derive their logical origin, nor their organization such that their output can be predicted. Formally these structures are related to mathematical chaos. The Swedish micro–to–macro model of the experimentally organized economy also belongs to this class of non–decodable structures. In the M–M model unpredictable behavior at different levels of aggregation derives from differently specified behavioral characteristics of agents. Unpredictable, chaotic behavior occurs in non–linear deterministic

models that exhibit contractionary and expansionary tendencies (Saari 1989). The origin of such phenomena was originally seen to be (Carleson 1989) true complexity. Hence chaos exhibits similarities with probabilistic behavior. The new awareness, however, is that using appropriate specifications (Day 1975a, b, 1983) chaotic behavior can occur in fairly simple and well known economic models.

This paper has demonstrated the impossibility of the "macroeconomic learning paradigm" entered as a prior in Keynesian and general equilibrium theory (e.g. to carry out welfare improving policies). I have used the Swedish micro–to–macro model as a reference ("reality") to discuss the possibilities agents have to decode its design, using external data and statistical learning techniques. The critical argument is that the policy authority in the non–learnable environment of the experimentally organized economy has no information advantage over any other agent. The situation is the reverse. The policy authority is a monopolist that significantly influences the entire economic system, thus making it still more difficult to predict the consequences of policies. The policy authority, hence, has to tread very cautiously in order not to do more harm than good. The auctioneer is a smart design trick, indeed by the neoclassical economists, making it possible for the Government of Economic Theory to always do right by definition. The Swedish MOSES model is no equilibrium model in which you can determine – from a location outside the economy – a positioning of the economy that is better than all other positionings. Such theory, inevitably, breeds centralistic, state elitist thinking, and if the economy has no equilibrium, policies based on such models easily lead to negative long term economic consequences.

Figure 1 MIP-principle and profit targeting (one firm)

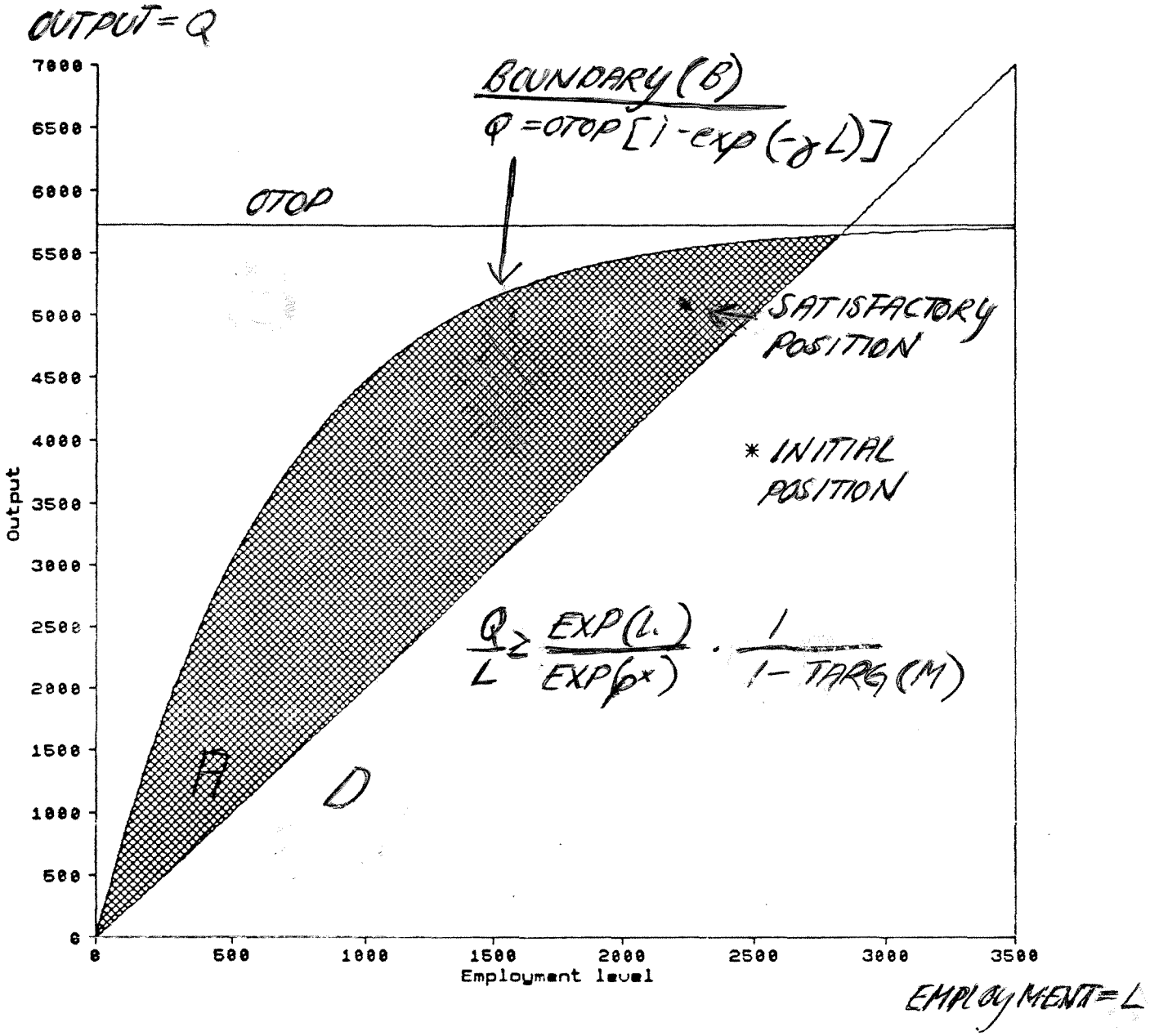
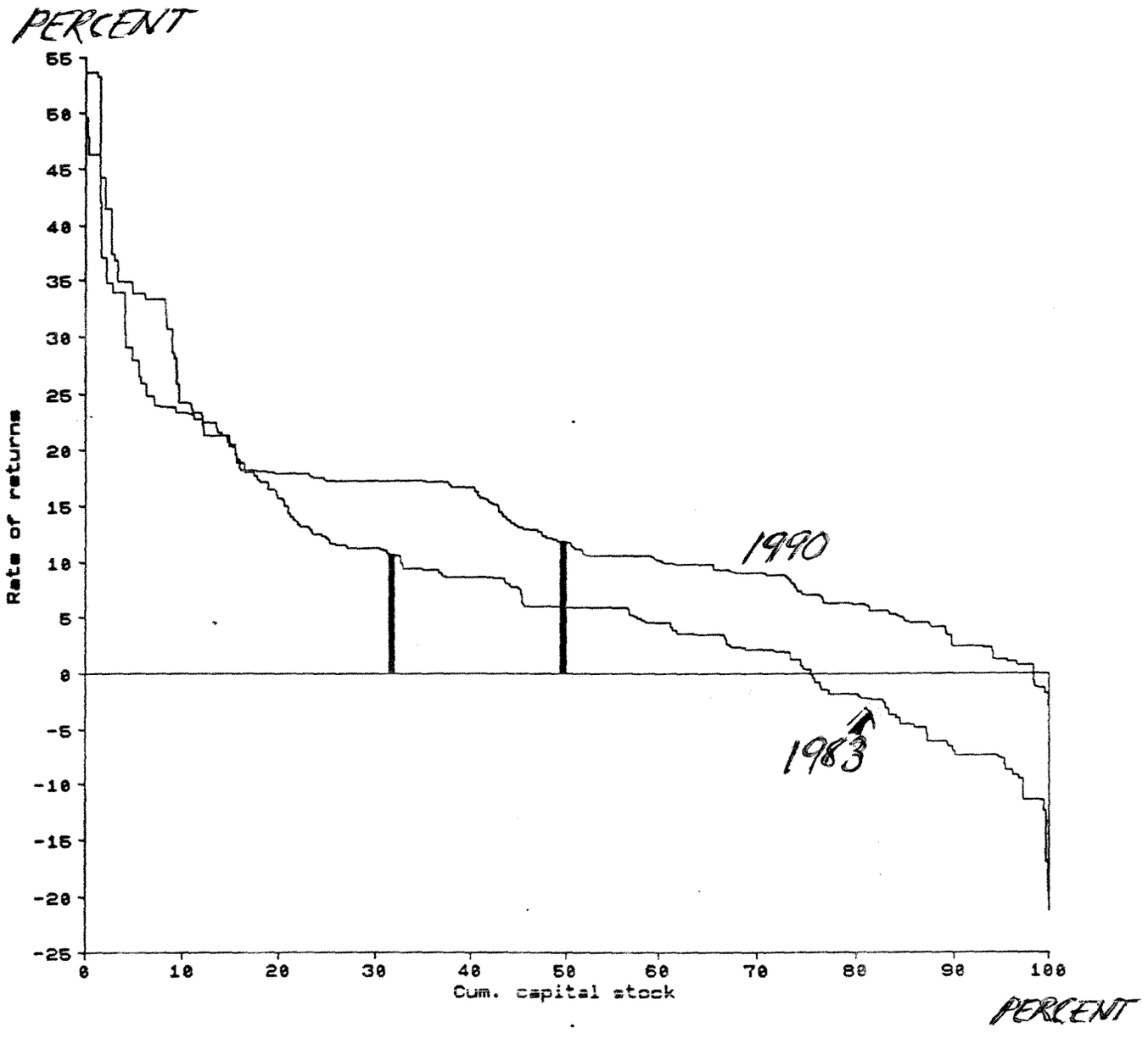
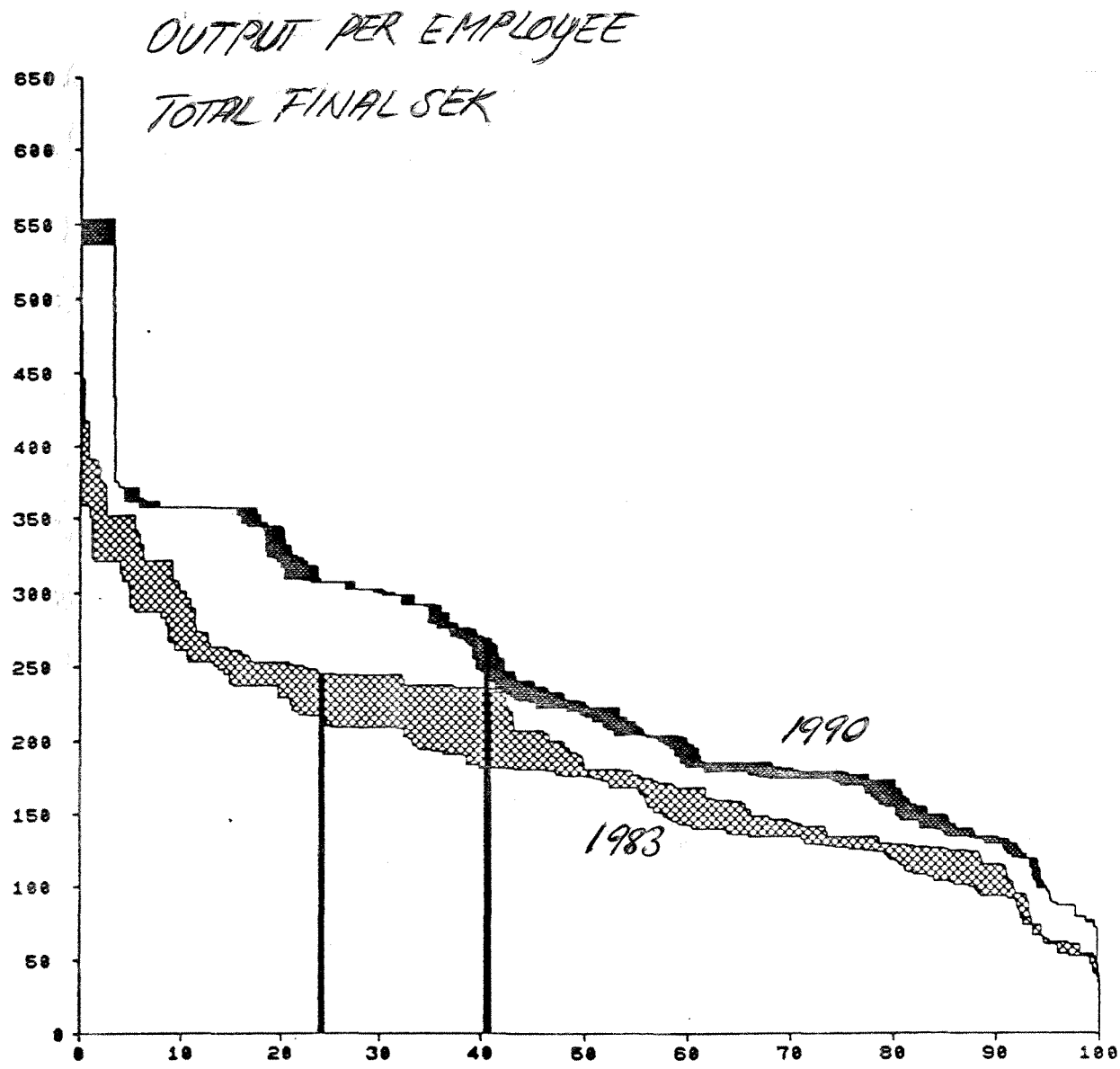


Figure 2A Excess rates of return (= $\hat{\epsilon}$) distributions 1983 and 1990



Source; Initial state, beginning of year 1983 and BASE experiment projections to 1990. See Taymaz (1991).

Figure 2B Actual and potential labor productivity distributions 1983 and 1990



Note: Shaded areas denote unused labor capacity (labor hoarding).

Source: Initial state, beginning of year 1982 and BASE experiment projections to 1990. See Taymaz (1991).

Figure 3A Total manufacturing output 1983–2015 in BASE, EQU 1 and EQU 2 experiments

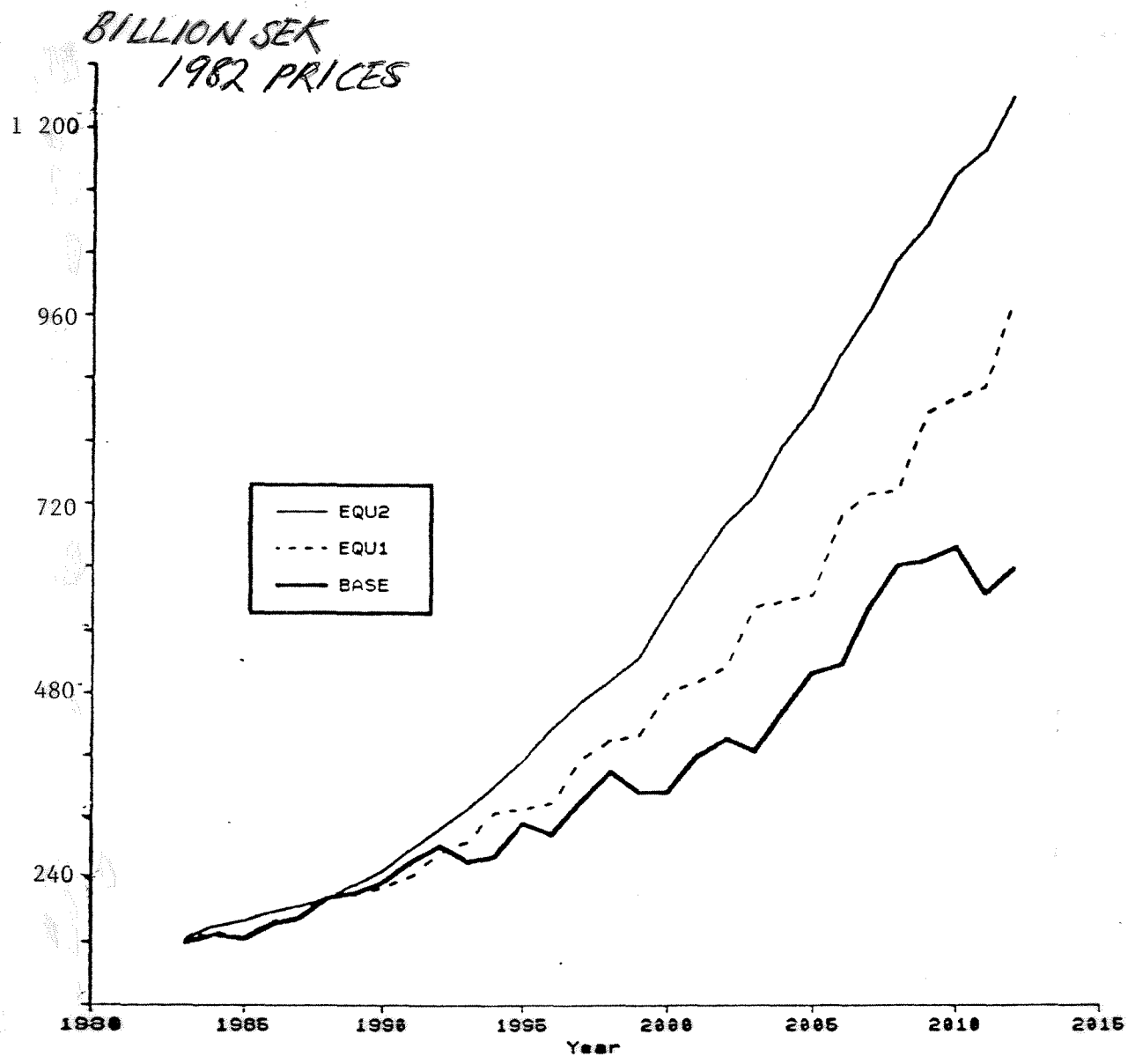


Figure 3B Macro output in capital goods manufacturing sector 1983–2012 in BASE, EQU 1 and EQU 2 experiments

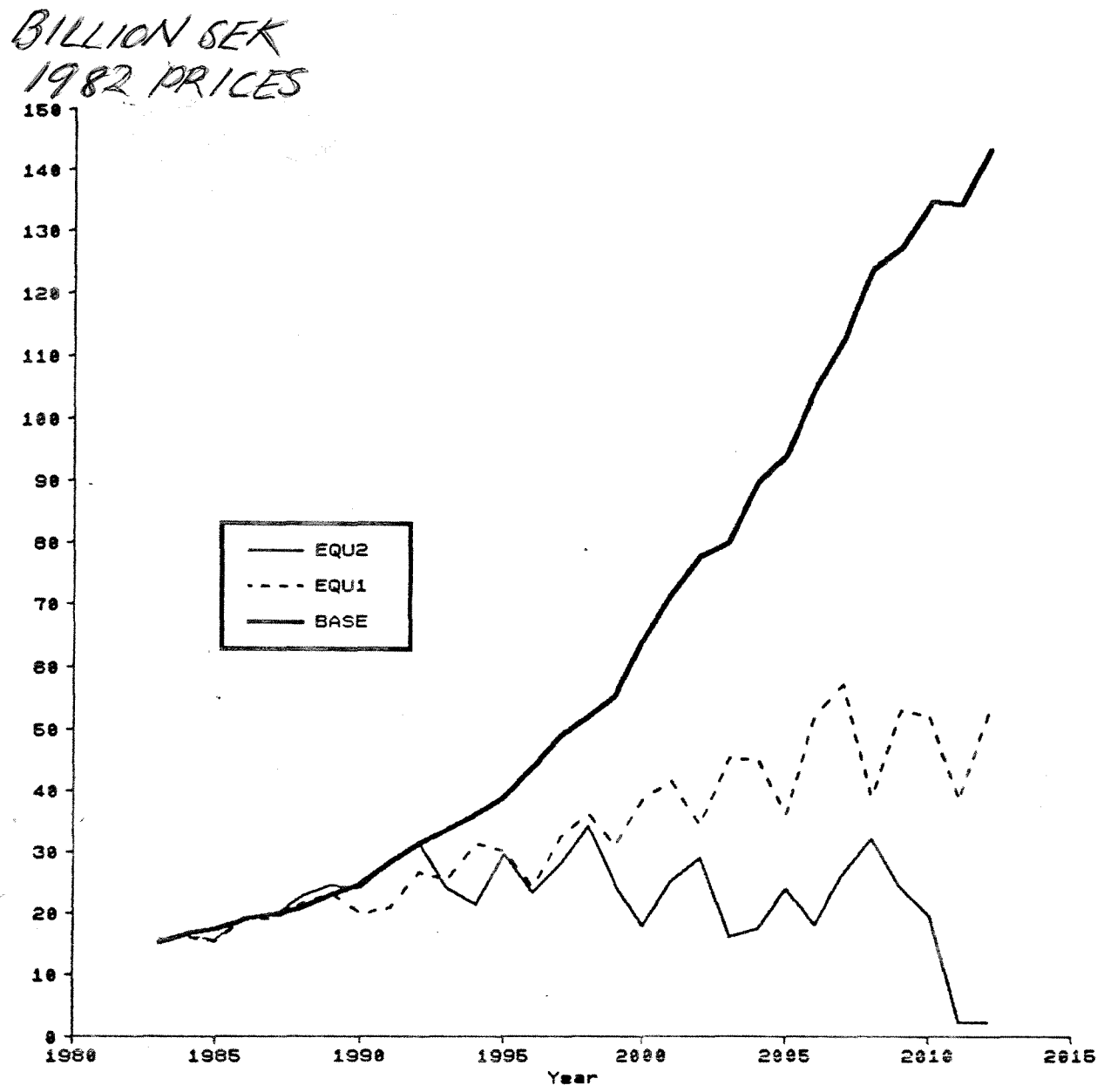


Figure 3C Average expected $\hat{\varepsilon}$ 1983–2012 in BASE, EQU 1 and EQU 2 experiments

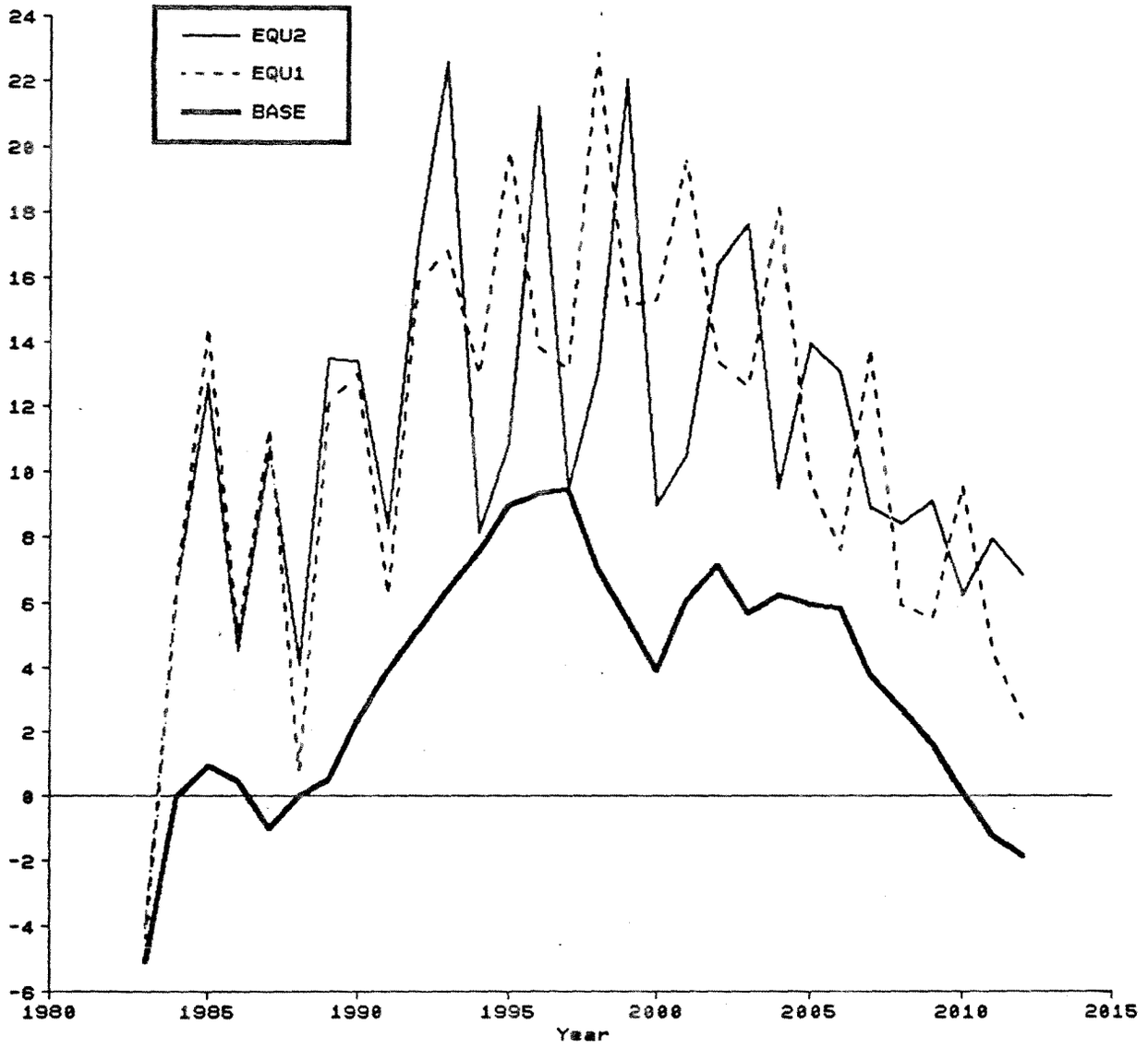


Figure 3D Average ex post $\hat{\varepsilon}$ 1983–2012 in BASE, EQU 1 and EQU 2 experiments

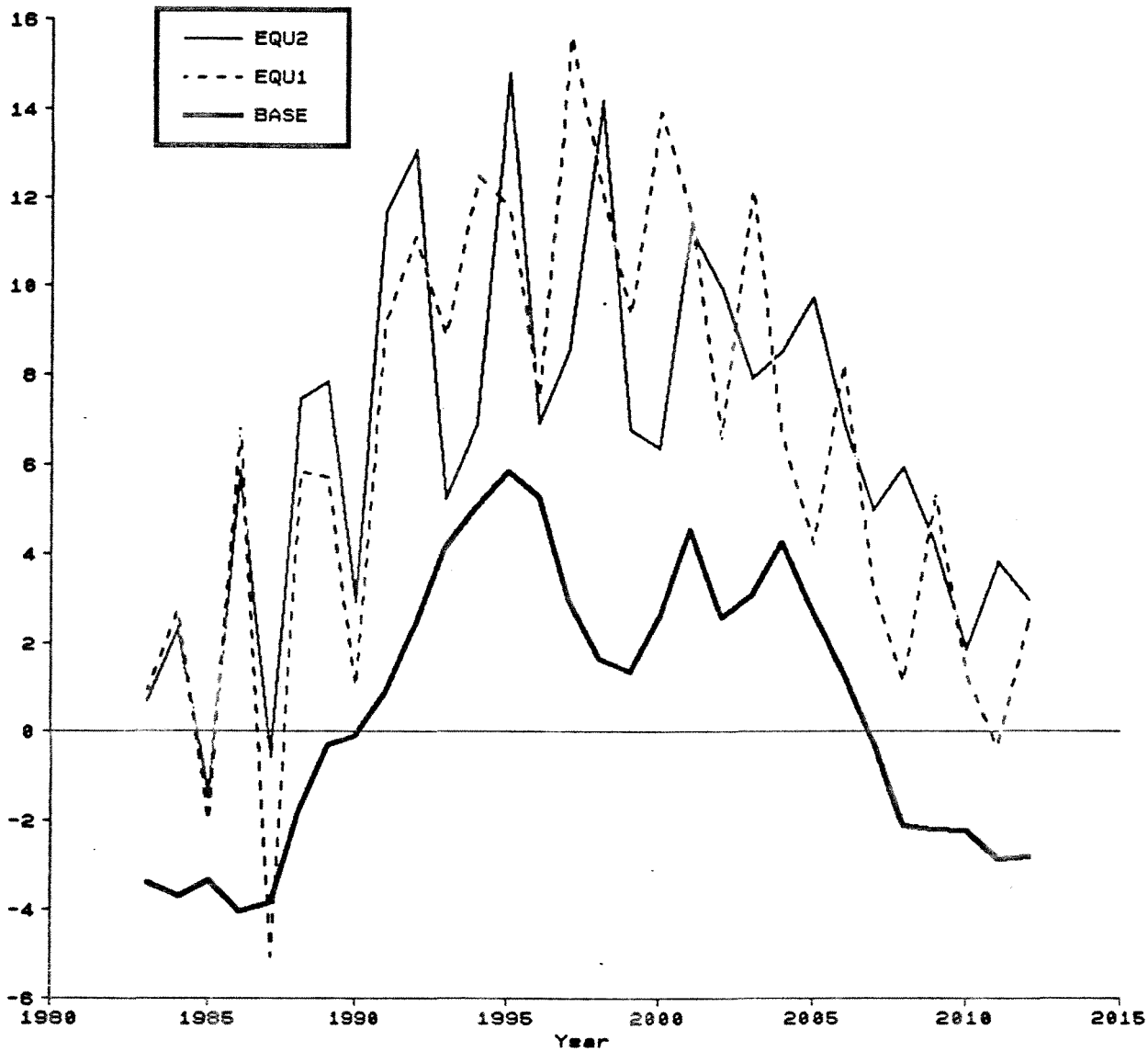


Figure 3E Average expected – ex post $\hat{\varepsilon}$ differences (realizations) 1983–2012 in BASE, EQU 1 and EQU 2 experiments

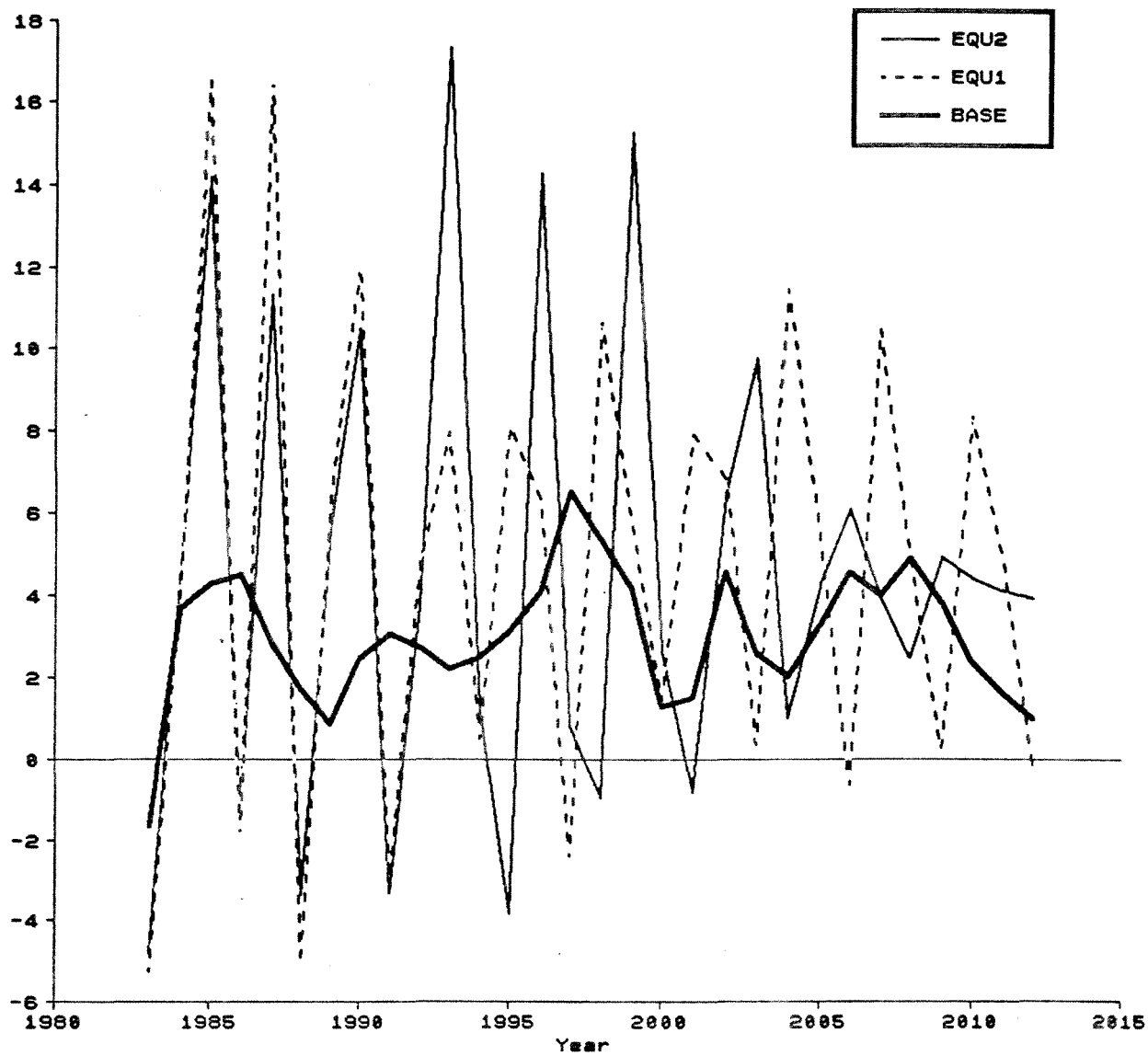


Figure 3F Manufacturing investment level 1983–2012 in BASE, EQU 1 and EQU 2 experiments

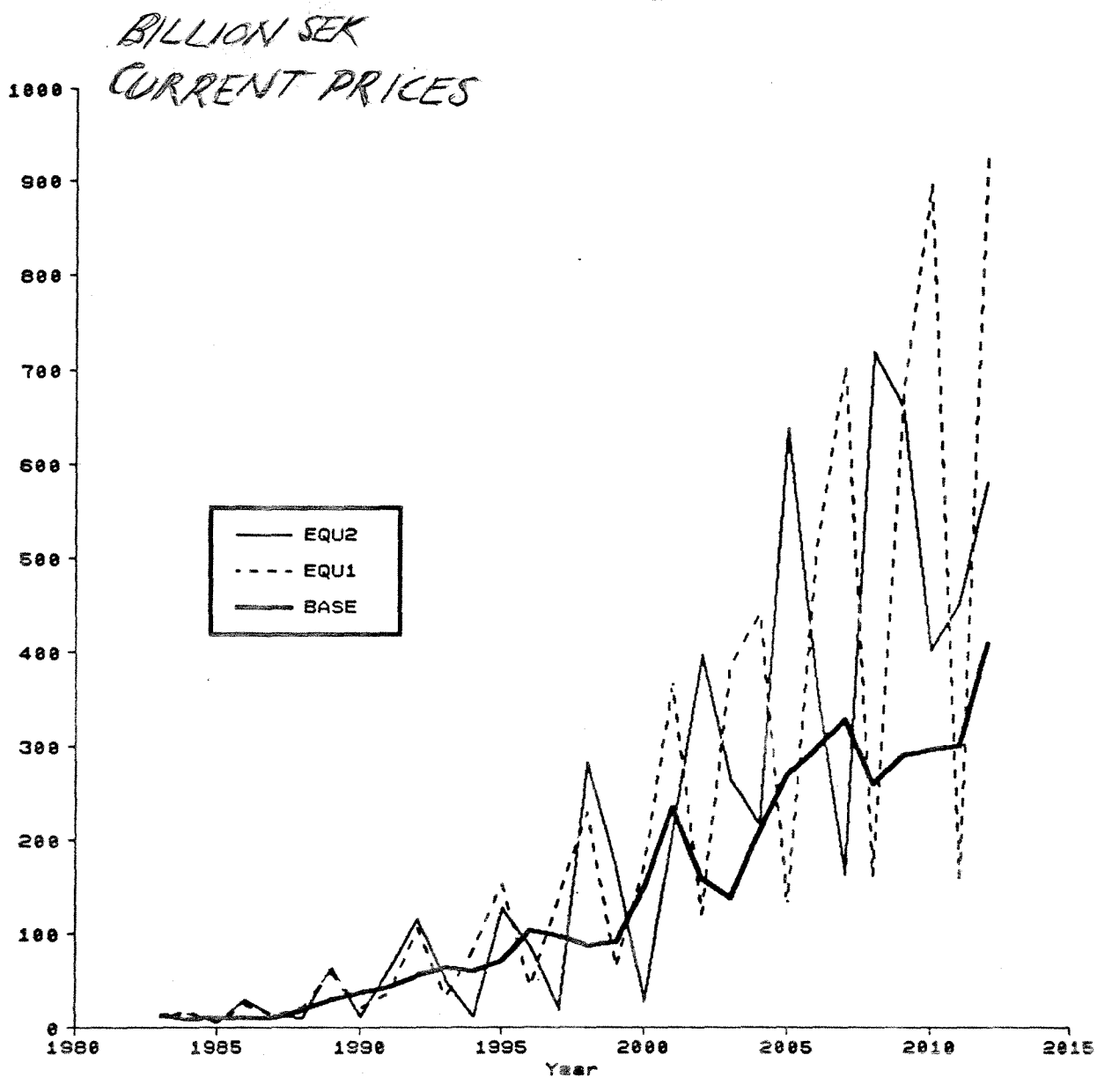


Figure 3G Interest (=r) 1983–2012 in BASE, EQU 1 and EQU 2 experiments

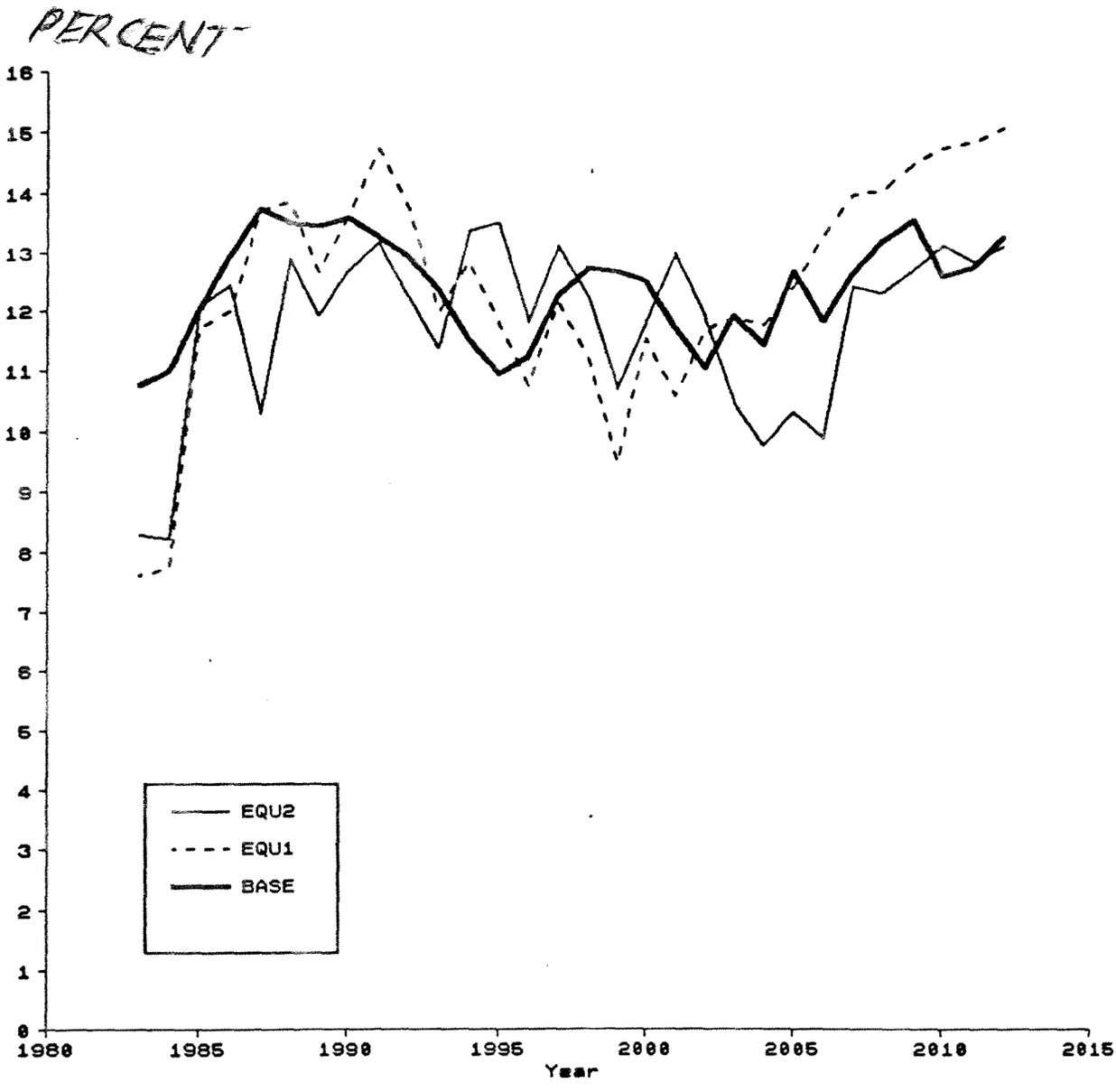
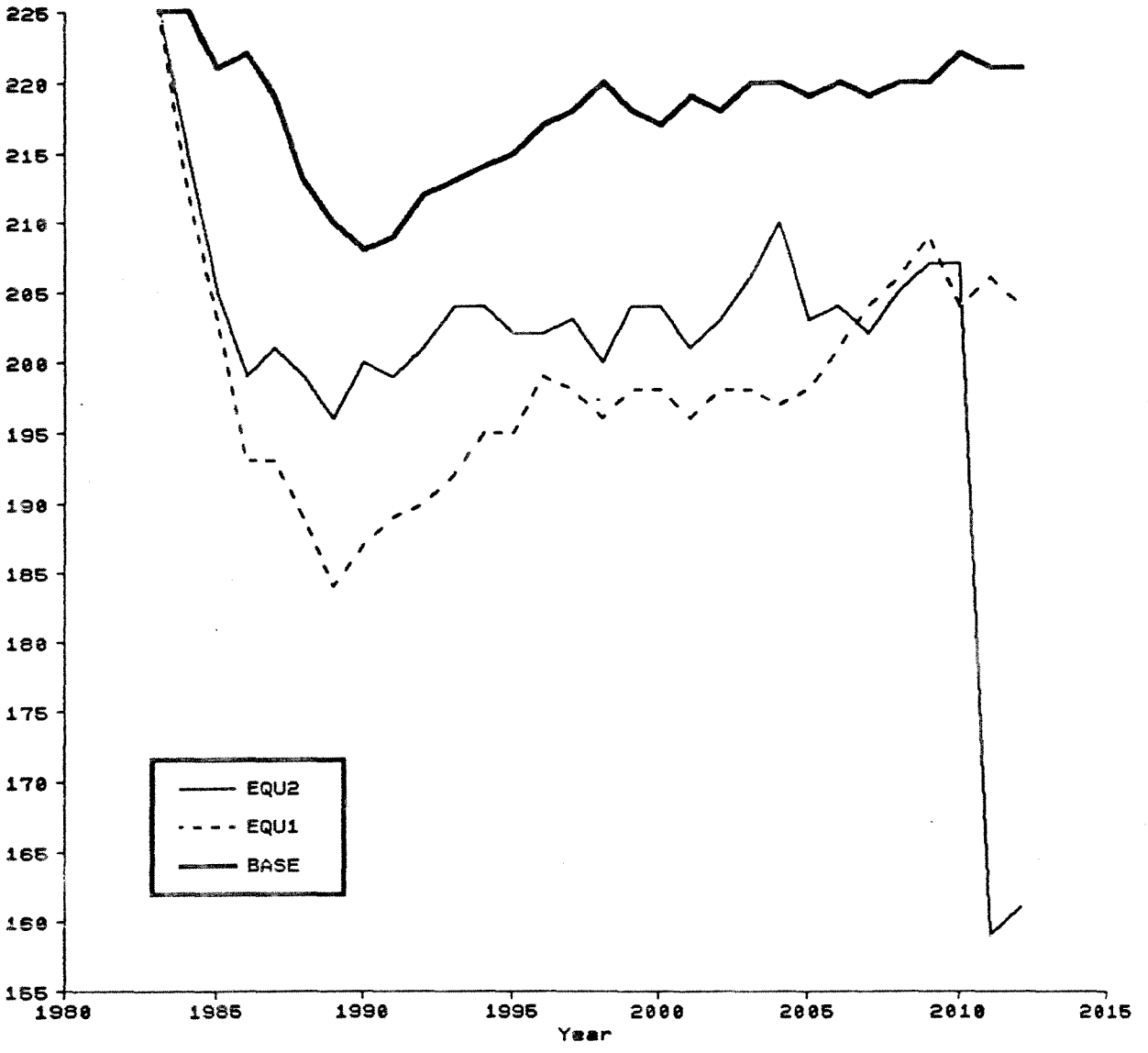


Figure 3H Number of firms in manufacturing sector 1983–2012 in BASE, EQU 1 and EQU 2 experiments



Figures 4 **Ex ante/ex post $\hat{\epsilon}$**
The realization function

Figure 4A **Distributions over firms of expected/ex post differences $\hat{\epsilon}$ years 1983, 1992, 2002 and 2012 in BASE experiment**

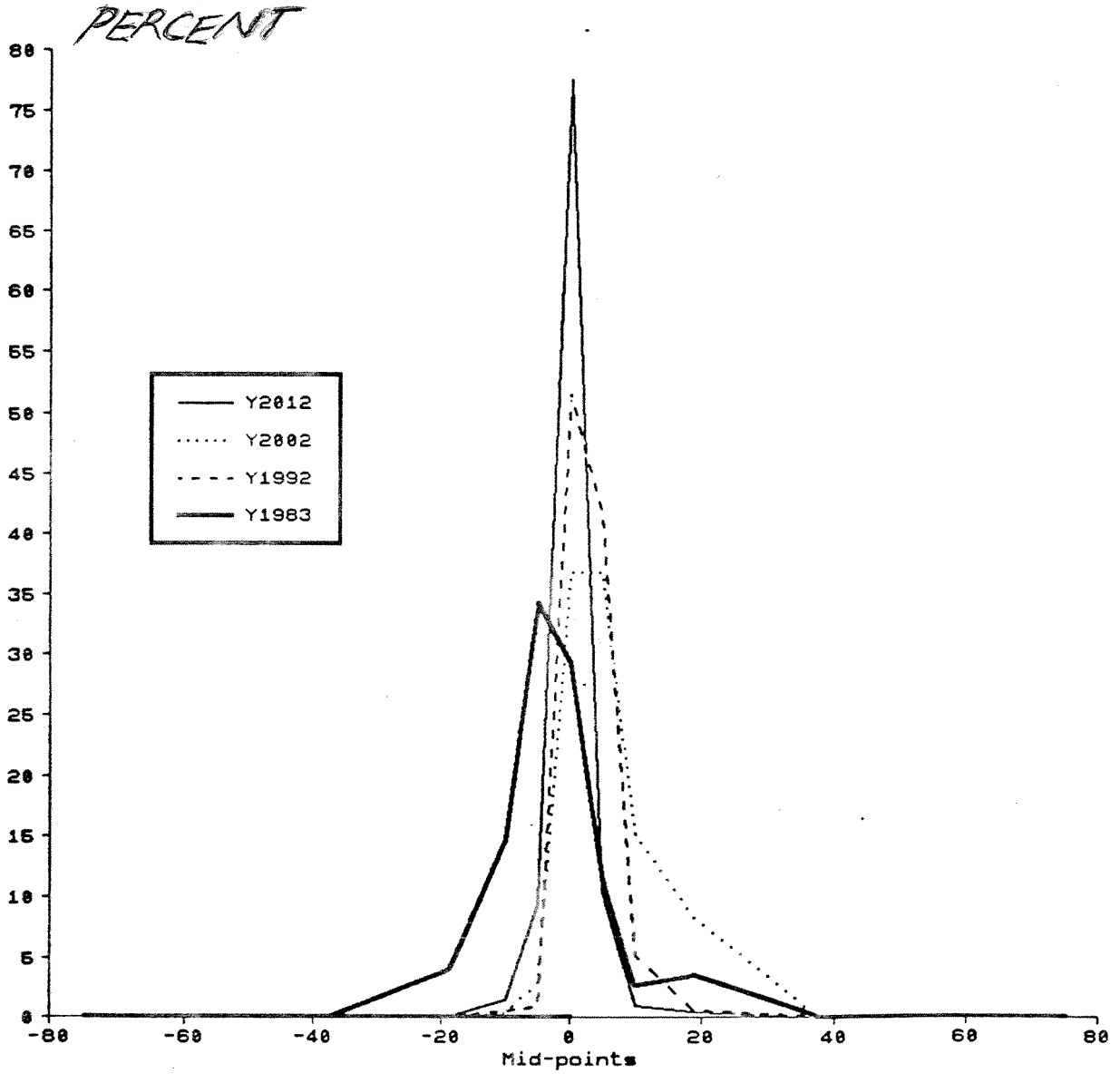
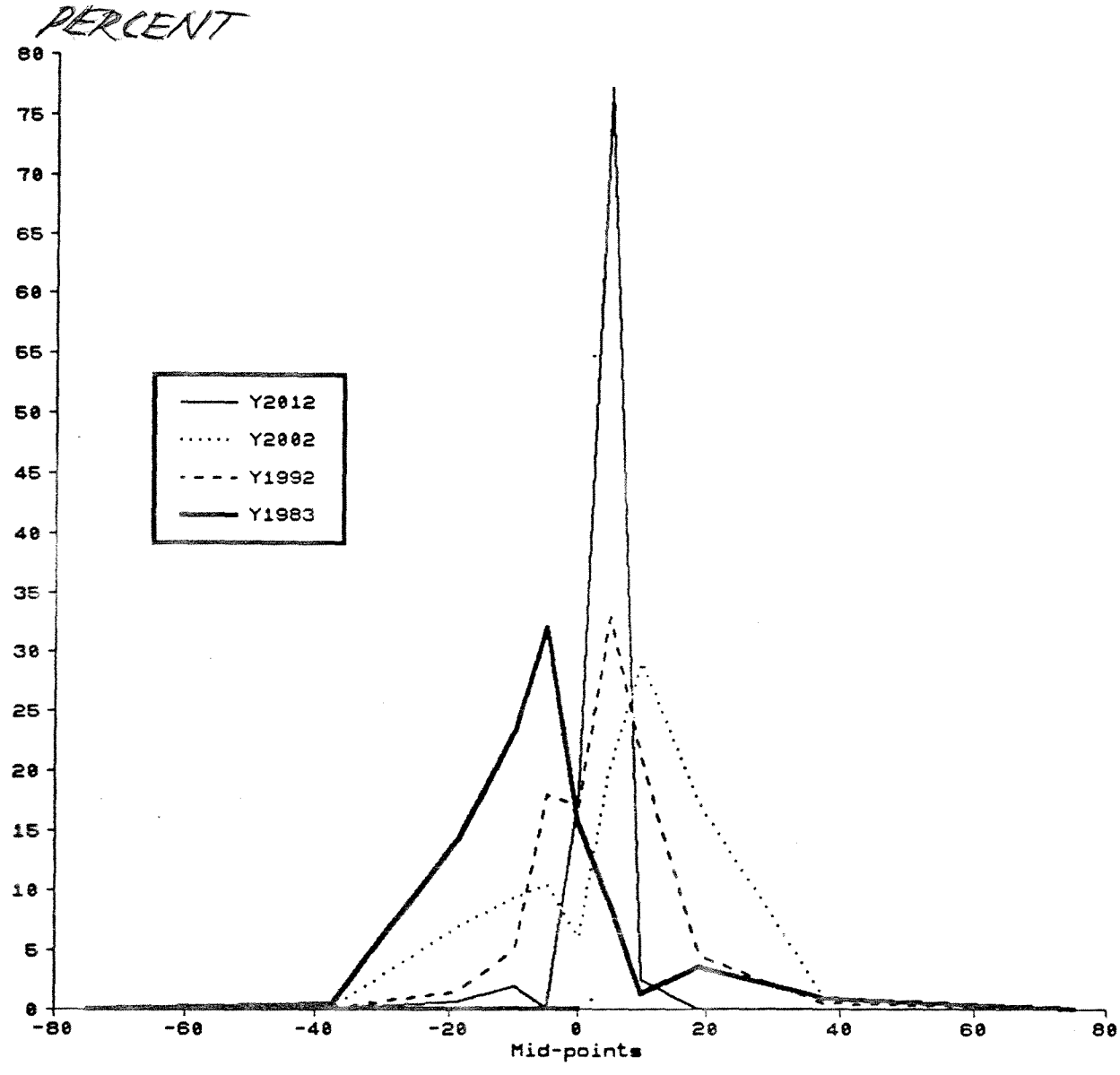


Figure 4B Distributions over firms of expected – ex post $\hat{\epsilon}$ differences years 1983, 1992, 2002 and 2012 in EQU 2 experiment



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