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# Competition Between Architectures

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**ABSTRACT.** – This paper investigates the relationship between the internal and industrial organization of firms. It is shown that a hierarchy and polyarchy (SAH and STIGLITZ [1985]) might exist in equilibrium and that more competition results in more centralized internal structures. Strategic aspects of the internal organization choice are also considered.

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## Concurrence entre architectures

**RÉSUMÉ.** – L'article étudie les relations entre organisation de l'industrie et choix d'organisation interne des firmes. On montre qu'une hiérarchie et une polyarchie (SAH et STIGLITZ [1985]) peuvent coexister à l'équilibre d'un marché et que la concurrence entre firmes est favorisée par l'adoption de structures internes centralisées. Des aspects stratégiques des choix d'organisation interne des firmes sont considérés par ailleurs.

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# 1 Introduction

Industrial organization has traditionally been concerned with the competition between firms at the market level of analysis. Firms are choosing strategies and taking actions in order to maximize profits and their interactions result in an industry equilibrium. This approach is rather silent about the internal functioning of firms due to the level of aggregation that is adopted. The firm is treated as a black box, which implies that the decision processes and procedures are taken for granted. However, the way in which firms are internally organized might have consequences for their behaviour in the market.

This paper investigates the relationship between the internal and industrial organization of firms. There are many internal organization choices to be taken, but we focus on how different evaluations of the same project are aggregated into an organization decision. There are many examples of such choices. All members of the security council of the United Nations evaluate each issue and cast their vote. Decisions require unanimity. Members of parliament vote on many different issues. The adoption of a new law is usually done by majority voting, but constitutional changes require a two third majority. Scientific journals base their acceptance of a paper on reports of referees. The journal has to decide how many referees will evaluate a paper, whether a paper is evaluated simultaneously or sequentially and how their reports are put into a journal decision. A firm has to decide whether a research proposal can be adopted in a decentralized fashion or has to get the approval by many different bureaus. A judicial system has to take some decisions regarding the possibilities of appeal. An accounting firm checking the annual reports of their clients has to decide internally whether a rejection of a report by one of their employees should be checked again or not.

Some aspects of the variety of decision procedures are dealt with in this paper. The internal organization choice is referred to as the choice of architecture (Sah and Stiglitz [1985]). An architecture describes how individual or local decisions are aggregated into an organization decision. Many different aggregation rules are possible, but we will limit ourselves to two extreme possibilities. A polyarchy accepts a certain project when there is at least one individual supporting the project. The adoption of a research project in universities provides an example. If some member of the scientific community considers a project as promissing, then (s)he carries it out. A hierarchy only accepts a project when everybody is favoring it.[1] The above example of the security council provides an illustration.

1. This use of terminology is inspired by electrical systems theory. The design of a relay circuit (architecture) may be such that the relays (individuals or local bureaus) are placed in series (hierarchy) or in parallel (polyarchy).

The performance of the different institutional arrangements is analyzed by investigating their incidence of failure and success and their associated payoffs. Four kinds of decisions are distinguished: a good (bad) project is either accepted or rejected. Failures are modelled as type-I and type-II errors. The probability of rejecting good projects is called a type-I error, whereas the probability of accepting bad projects is a type-II error. A polyarchy and hierarchy differ with respect to the probability of accepting good and bad projects. A polyarchy accepts a larger percentage of projects than a hierarchy. This is true for good as well as bad projects. More decentralized structures like a polyarchy have therefore a relative advantage in accepting good projects, whereas a more centralized structure is preferred when rejecting bad projects is of primary importance.

These architectures are quite often embedded in a market environment. Universities compete for Ph-D students. Each candidate is screened by several faculty members. The question addressed in this paper is whether the architecture choice of a university is influenced by having other universities around. The same question applies to the adoption of projects by firms. However, a distinction has to be made between projects that can be carried out by only one firm and projects which may be adopted by more than one firm. An example of the first case is the construction of a bridge or the above example of the Ph-D students. The development of a new drug illustrates the second case, because several firms may start independently with it. This second case will be treated in this paper.

We are analyzing the industrial organization effects of the internal organization choice by considering a model in which two architectures are competing against each other. Suppose there are zero, one or two firms in the market, which depends on their evaluations of the project. There are zero firms in the market when both architectures reject a project. A firm is a monopolist when it accepts a project and the other firm rejects it. It is assumed that the firms share the market when they both accept the project. So, a firm accepting a project is either a monopolist or duopolist, depending on the acceptance decision of the rival firm. The loss incurred due to accepting a bad project is assumed to be independent of market structure.

Several results emerge from the analysis. An increase in the difference between the acceptance probabilities of good projects of a polyarchy versus a hierarchy favors the acceptance of a polyarchy in both a monopoly and duopoly. The same result emerges when the difference between acceptance probabilities of bad projects is decreasing. The reason is that a polyarchy is relatively good at accepting projects, whereas a hierarchy is better at rejecting projects. The comparative statics results with respect to the benefits of a good project, the costs associated with selecting a bad project and the portfolio composition are similar. An increase in the benefits associated with a good project, a decrease in the costs associated with a bad project and an improvement in the portfolio composition favor more frequent acceptance of project proposals. A polyarchy performs best in this respect.

A duopoly consisting of two hierarchies is predicted for a larger set of parametervalues than the choice of hierarchy by a monopolist. More competition results in firms having an internal organization structure which is more hierarchical. The explanation for this counterintuitive result is that competition reduces the probability of being the only one in the market. The market has to be shared with a competitor once in a while. It reduces therefore the expected value of accepting a good project. The reduction of Type-II errors becomes therefore more important and hierarchies are relatively good at preventing these errors.

Two different architectures may coexist in equilibrium. Such an equilibrium generates a higher payoff for a polyarchy because it faces a higher expected revenue of accepting a good project in either a monopoly or duopoly. This is due to the polyarchy having a higher probability of selecting a good project. This effect compensates for being more often on the wrong track. One hierarchy is sustained because the lower expected costs of accepting bad projects outweighs the reduction in the expected revenue of accepting a good project in either a monopoly or duopoly. This latter effect is due to the hierarchy having a lower probability of selecting a good project.

A prisoners dilemma may also emerge. Suppose that both firms adopting a hierarchy maximizes their joint payoff. Deviating from the (H, H)-equilibrium is attractive because the expected revenue of winning in either a monopoly or duopoly is increased. This effect compensates for the costs of being more often on the wrong track. The profits of the remaining hierarchy are decreased by the switch of the competitor, because the probability of being a monopolist is reduced. This hierarchy will be abandoned for the same reasons as the move of the other architecture from a hierarchy to a polyarchy. There are no parametervalues for which two hierarchies form a prisoners dilemma in the above model.

Strategic considerations may also play a role in the choice of architecture. Suppose that the only profitable duopoly configuration for the entrant consists of two hierarchies. A monopolist may choose a hierarchy in the absence of entry, whereas the threat of entry forces the monopolist to choose a polyarchy. The increased probability of facing the incumbent decreases the attractiveness of the market to such an extent that entry is not profitable anymore, even though the entry fee is zero. The incumbent sacrifices therefore some monopoly profits by not adopting a hierarchy in order to deter entry.

There have recently been a number of other papers linking the internal and industrial organization of firms. These papers are not closely related, but their structure is similar. Willig [1986] analyzes management performance as a function of exogenously given market conditions, Fershtman and Judd [1987] and Vickers [1985] study the effects of delegation on market rivalry, Nalebuff and Stiglitz [1983] and Hart [1983] focus on the use of market competition as a mechanism for assessing management performance and mitigating moral hazard problems, and Bull and Ordover [1987] investigate the relationship between the decision rule for rejecting projects, the degree of competition and the size of the organization. Brander and Lewis [1986] and Maksimovic [1988] look at oligopoly and financial structure, Bonanno and Vickers [1988] and Coughlan and Wernerfelt [1989] analyse oligopoly and vertical separation. Schwarz and Thompson [1986] consider divisionalisation in order to preempt entry in a homogeneous product world, whereas HENDRIKSE [1991] analyzes the use of divisions in a heterogeneous product world. GLAZER and ISRAEL [1990] look at managerial incentives and financial signalling in product markets.

The paper is organized as follows. Section two presents the architecture choice. Section three derives and explains the results. Finally, conclusions and avenues for further research are offered.

# 2 The Model

A firm is defined as a collection of bureaus. Each bureau evaluates projects and decides to either accept (A) or reject (R) a project. The pool of projects faced by a bureau consits of good and bad projects. A good project generates a positive payoff, whereas a bad project has a negative return.

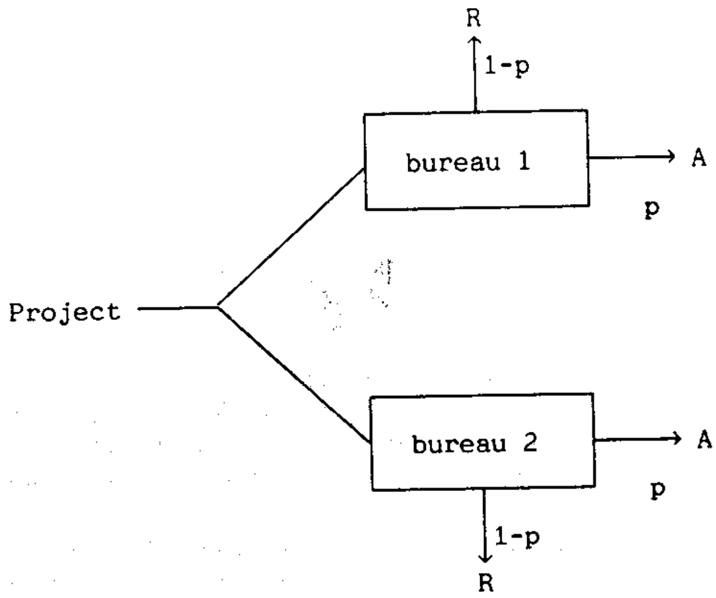
It is assumed that there are errors of judgment involved in deciding which project to adopt. This is modelled by incorporating a probability that a bad project is accepted and a probability that a good project is rejected. The incidence of type errors made by an organization is influenced by the way in which individual decisions are aggregated into an organization decision. SAH and STIGLITZ [1985] have modelled this by defining a hierarchy as an organization which only accepts a project when there is unanimity between all bureaus, whereas a polyarchy only rejects a project when every bureau rejects it.

It is assumed that every individual (bureau) is evaluating/sampling the same projects and that this is done independently. Suppose that a bureau is accepting a project with probability $p$ and that a firm consists of two bureaus. Figure one represents this situation graphically. A polyarchy will accept a particular project with probability $p(2-p)$, whereas this probability is $p^2$ for a hierarchy.

The composition of the portfolio of projects is characterized by $\alpha$, which is defined as the porportion of good projects in the pool of available projects. A particular project is therefore good or bad, which has to be reflected in the probability $p$. This probability is a conditional probability and we define therefore more specifically $p(A \mid B)$ as the probability that a bad project is accepted and $p(A \mid G)$ as the probability that a good project is accepted. The acceptance probability of a firm depends on five aspects. They are the nature of the project, the composition of the portfolio, the acceptance probability of a particular bureau, the number of bureaus and the architecture choice of the firm. The acceptance probability of a bad project by a hierarchy with two bureaus is $(1-\alpha)p(A \mid B)^2$. Similarly, a polyarchy with two bureaus accepts a good project with probability $\alpha p(A \mid G)(2-p(A \mid G))$.

FIGURE 1

***Firm as a Collection of Bureaus***




It is sufficient for our purposes to deal with the probabilities of accepting good and bad projects for the architecture as a whole. Define $f_H$, ($f_P$) as the probability that a hierarchy (polyarchy) is accepting a good project and $g_H$, ($g_P$) as the probability that a hierarchy (polyarchy) is accepting a bad project. A polyarchy with two bureaus has therefore

$$f_p = p(A \mid G)(2 - p(A \mid G)).$$

It follows immediately from the definitions of a hierarchy and a polyarchy that

$$f_H < f_P$$

and

$$g_H < g_P,$$

*i.e.* a polyarchy accepts a larger proportion of good as well as bad projects compared to a hierarchy.

It is assumed that there is some filtering *i.e.* the probability that a bad project is judged to be good is smaller than the probability that a good project is accepted ($p(A \mid B) < p(A \mid G)$). This implies that

$$g_H < f_H$$

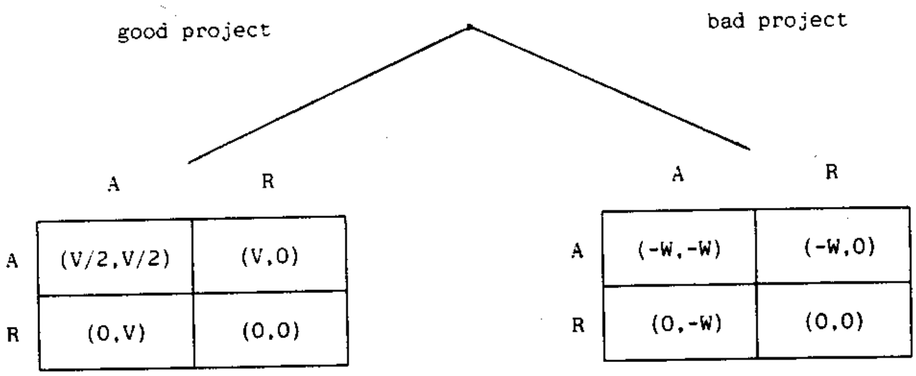
and

$$g_P < f_P.$$

The present value of costs associated with accepting a bad project are defined to be W, whereas a good project generates a payoff of V. The duopoly case involves two values of accepting a good project. It depends on the decision of the rival whether the market has to be shared or not. We assume that the gains associated with a good project are split equally when both architectures accept the project. The loss associated with accepting a bad project is assumed to be independent of market structure. Figure two summarizes these assumptions.

FIGURE 2

***Acceptance Decisions and Duopoly Payoffs***




# 3 Results

The results of the above model are derived and explained in this section. We examine first the monopoly case en subsequently the competition between two architectures.

The expected profits of a monopolist having architecture $i$ are

$$Y_i = \alpha f_i V - (1-\alpha) g_i W.$$

It is straightforward to show that

$$Y_P > Y_H \Leftrightarrow \frac{f_P - f_H}{g_P - g_H} > K,$$

where

$$K = \frac{(1-\alpha) W}{\alpha V}.$$

The comparative statics results regarding the architecture choice by the monopolist follow immediately from this expression. An increase in the benefits associated with a good project (V), an improvement in the portfolio ($\alpha$) and a decrease in the costs associated with a bad project (W) increase the range of parameters for which a polyarchy is chosen.

The expected profits of a firm having architecture $i$ and facing a competitor with architecture $j$ are $Y_{ij}$. We have therefore

$$Y_{ij} = \alpha f_i (f_j V/2 + (1 - f_j) V) - (1 - \alpha) g_i W.$$

The profit-maximizing architecture choice in a noncooperative setting is determined by a Nash equilibrium. It can be shown that

$$\text{(H, H)-equilibrium when } \frac{f_P - f_H}{g_P - g_H} < L$$

$$\text{(H, P)-equilibrium when } L < \frac{f_P - f_H}{g_P - g_H} < M$$

$$\text{(P, P)-equilibrium when } M < \frac{f_P - f_H}{g_P - g_H},$$

where

$$L = \frac{(1-\alpha) W}{\alpha V (1 - f_H/2)}$$

and

$$M = \frac{(1-\alpha) W}{\alpha V (1 - f_P/2)}.$$

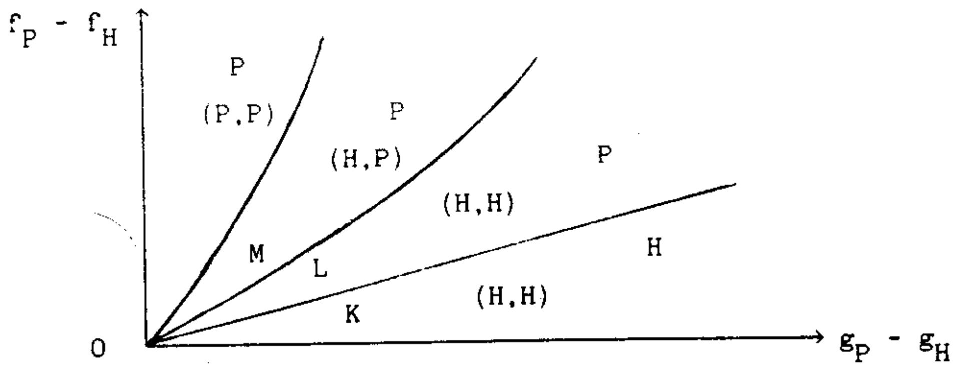
The results are presented in figure three. Four segments of the parameter space are distinguished in order to represent the profit maximizing architecture choice in the monopoly as well as the duopoly situation. The upper array of symbols indicates the profit maximizing architecture choice by a monopolist. Duopoly choices are reflected by the second array. Finally, the array most close to the origin determines the demarcation of the segments.

The duopoly choices deserve some comments. An increase in the difference between the acceptance probabilitites of good projects favors the acceptance of a polyarchy in both a monopoly and duopoly. The same result emerges when the difference between acceptance probabilities of bad projects is decreasing. The reason is that a polyarchy is relatively good at accepting projects, whereas a hierarchy is better at rejecting projects.

The comparative statics results with respect to the size of the four segments is determined by the characteristics of the portfolio of projects. The prize of winning (V), the costs associated with selecting a bad project (W) and the portfolio composition ($\alpha$) have similar effects. A higher prize (lower costs, improved portfolio) will increase to expected payoff of a project and therefore increase the range of parametervalues for which a polyarchy is accepted.

FIGURE 3

***Architecture Choice in a Monopoly and Duopoly Market***




A duopoly consisting of two hierarchies is predicted for a larger set of parametervalues than the choice of hierarchy by a monopolist. Competition reduces the probability of getting all the benefits from a good project and therefore the expected value of a good project. It becomes more important to reduce Type-II errors and hierarchies are relatively good at preventing these errors. Notice that this result of more competition resulting in more centralized decision structures depends on our assumption that benefits have to be split in duopoly, whereas costs are independent of market structure.

The assumption regarding the costs of accepting a bad project may be relaxed by the introduction of a parameter depending on market structure. The theoretical literature on innovation regarding R & D outlays of firms and the number of firms in the market is unsettled regarding the size of this parameter. It is not clear whether industry outlays increase or decrease when the number of firms in the industry is changing (REINGANUM [1989]). A reduction in costs when there are two firms in the market instead of one will reduce K, L and M. Type II-errors are less expensive and a polyarchy will be chosen for a larger set of parametervalues. It is straightforward from the expressions of K and L that the above result continues to hold when costs don't decrease below a fraction $1-f_H/2$ of W. This fraction is larger than .5 because the firms earn an average of V and V/2 in duopoly.

Two different architectures may coexist in equilibrium. Such an equilibrium is attractive for a polyarchy because it faces a higher expected revenue of good projects in either a monopoly or duopoly. This is due to the polyarchy having a higher probability of selecting a good project. This effect compensates for being more often on the wrong track. One hierarchy is sustained because the lower expected costs of accepting bad projects outweighs the reduction in the expected revenue of accepting a good project in either a monopoly or duopoly.

FIGURE 4

***Architecture Choice and Prisoners Dilemma***

| | H | P |
|---|---|---|
| H | (10.76,10.76) | (6.44,18.44) |
| P | (18.44,6.44) | (8.36,8.36) |

FIGURE 5

***Architecture Choice and Entry Deterrence***

| | H | P |
|---|---|---|
| H | (1.75,1.75) | (-.28,-17.76) |
| P | (-17.76,-.28) | (-20,-20) |

The above effects explain the emergence of a prisoners dilemma. Parametervalues can be chosen such that two polyarchies form a prisoners dilemma. Figure four presents this situation with parametervalues $f_H = .36$, $f_P = .84$, $g_H = .16$, $g_P = .64$, $\alpha = .5$, V = 100 and W = 50. Deviating from the (H, H)-choices is attractive because the expected revenue of good projects is increased in a monopoly as well as a duopoly. This effect compensates for the costs of being more often on the wrong track. The profits of the remaining hierarchy are decreased by the switch of the competitor, because the probability of being a monopolist is reduced. This hierarchy will be abandoned for the same reasons as the move of the other architecture from a hierarchy to a polyarchy. There are no parametervalues for which two hierarchies form a prisoners dilemma in the above model.

Strategic considerations may also play a role in the choice of architecture. There are parametervalues such that a monopolist will choose a hierarchy in the absence of entry. However, the threat of entry forces the monopolist to choose a polyarchy because the entrant can't profitable enter with either a hierarchy or polyarchy, even though the entry fee is zero. Figure five provides a numerical illustration with $f_H = .9$, $f_P = .99$, $g_H = .46$, $g_P = .9$, $\alpha = .5$, V = 100 and W = 100. The only profitable duopoly configuration for the entrant consists of two hierarchies. An incumbent will prevent this situation to emerge by adopting a polyarchy. The profits of a monopolist decrease by choosing a polyarchy instead of a hierarchy, but monopoly profits with a polyarchy are still higher than those of a hierarchy in a duopoly. There are also parametervalues for which the opposite occurs.

# 4 Conclusions and Further Research

We have shown that the choice of architecture is determined by the number of competitors, decision theoretic as well as strategic considerations. Decision theoretic aspects were reflected by the probabilities of accepting and rejecting projects. The costs and benefits associated with bad and good projects determined the profit maximizing architecture choice. The number of competitors influenced this choice because the benefits of accepting a good project were reduced in the duopoly situation. This favored the adoption of a hierarchy. Strategic considerations may also have an effect on the aggregation rule adopted by the incumbent firm because it structures the expected payoffs of a potential entrant.

There are several other interesting issues to be addressed in this environment. Example are the optimal number of decision units in an architecture, (represented in $f_H$, $g_H$, $f_P$ and $g_P$) and the optimal degree of consensus (SAH and STIGLITZ [1988]). Third, the performance of the different architectures might be enhanced by taking into account the information generated by the decision of the lower bureau. A rejection in a polyarchy or an acceptance in a hierarchy might change the screening level choice of the higher bureau (MEYER [1991]). Fourth, the quality of the remaining pool of projects ($\alpha$) changes when a project is evaluated. Fifth, the result of more competition resulting in more centralized decision structures depends on the assumption that the investment costs associated with a bad project in a duopoly are of the same magnitude as those in a monopoly. A richer model might make these costs dependent on market structure, like in LOURY [1979], and on the internal organization choices. Finally, a topic not dealt with in this paper are incentive considerations.

Our analysis was geared to the industry level, but it might also be applied to evaluate the competition between economic systems. FUKUYAMA's claims [1990] about the end of history and the emergence of one world wide way of organizing economic systems is qualified from the perspective of the aggregation of local decisions. We have shown that a world with two hierarchies or one hierarchy and one polyarchy might emerge. The different composition of the portfolio of industries within these systems may further add to this variety.

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