ELSEVIER European Economic Review 39 (1995) 691–699

EUROPEAN ECONOMIC REVIEW

Information, Communication and Organizations

The time and budget constraints of the firm

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Abstract

This short paper surveys some recent research on the internal organization of firms, with an emphasis on task allocation and synchronization. It focuses on an organization facing no incentive problems but time constraints and costs of communication. It highlights two motives for communication: concern for delay and concern for throughput. It also considers the interaction between the time and budget constraints of the firm and its implication for organization design.

Keywords: Organization of firms; Time constraints; Budget constraints

JEL classification: L23

1. Introduction.

An individual agent's payoff maximization problem subject to time and budget constraints is a relatively well-defined problem: an individual has on average twelve to sixteen hours a day to divide between work and leisure; similarly, an individual's wealth is composed of his lifetime earnings plus bequests. The agent's problem is to maximize some utility function subject to these constraints.

* Corresponding author. We thank the 'Pôle d'Attraction Interuniversitaire' programme of the Belgian Government, which has supported this work under grant 26.

SSDI 0014-2921(94)00076-X

In contrast a multi-agent organization's maximization problem subject to time, technology and budget constraints is less well defined. To begin with, it is not clear that a perfectly competitive firm as described in most textbooks has time and budget constraints, since in principle the firm can hire an unlimited amount of labour and capital. Real firms, however, do have time and budget constraints but it is not easy to define them precisely. In particular, the firm's time constraint is not the sum of its agents' time endowments since typically not all agents' time can be usefully employed at all time. In order to use all agents' time most efficiently their tasks must be carefully parcelled out and synchronized.

The allocation of tasks and their synchronization is an important dimension of the design of the firm's internal organization. This is the main reason why the study of the firm's time constraint is both interesting and important.

As for the firm's budget constraint, it is determined to a large extent by the firm's retained earnings, the net present value of its future investments, the quality of its management as well as the liquidation value of its assets. Much recent work in corporate finance has been devoted to the study of the firm's budget constraint. The purpose of this short paper is not to review this research, but rather to highlight some important ways in which the firm's time and budget constraints are interconnected. At the same time this paper surveys some recent research on the internal organization of firms emphasizing the aspects of task allocation and synchronization (for extensive surveys on these issues see Radner (1992) and Van Zandt (1994)).

Most of the economics research on organizations has focused on incentive issues (see e.g. Milgrom and Roberts, 1992). It is only recently that issues of coordination and synchronization of tasks have been taken up by economists. This is somewhat surprising given the importance of these issues in managerial science and in economic history. For example, the leading economic historian of the corporation, Alfred Chandler (1966, pp. 382–383) explains as follows the emergence of the multidivisional firm: "The basic reason for the success (of the multidivisional form) was simply that it clearly removed the executives responsible for the destiny of the entire enterprise from the more routine operational activities, and so gave them time, information, and even psychological commitment for long-term planning and appraisal". At a theoretical level, Arrow (1974) and Simon (1981) have also stressed at length the importance of the design of communication flows in structuring organizations.

The plan of the paper is as follows. Section 2 details a general framework of an organization facing no incentive problems but time constraints and costs of communication. Section 3 highlights two aspects of time constraints that have been emphasized in relation with internal organizations: (i) concern for delay and (ii) concern for throughput. Finally, Section 4 considers the interaction between time and budget constraints.

Time and budget constraints are interconnected because time can be divided between the activities of identifying new investment opportunities and fine-tuning the allocation of available funds between already identified investment projects. Depending on the scarcity of capital one activity may be more valuable than the other. As is shown in Section 4, each activity involves different forms of internal organization.

2. The setup

We consider a continuous time, infinite horizon setup without discounting. For simplicity, we assume away any incentive problems between individuals in the organization. We concentrate entirely on information processing activities, leaving all other activities of the firm in reduced form. [1] The goal of the organization is to maximise its flow return of information, using individuals' time at a given hourly wage w.

Information arrives at equidistant dates $t = 1, 2, 3, \dots,$ in 'cohorts' composed of M items each. [2]. A cohort is 'processed' when at least one individual in the organization has absorbed all its items. A processed cohort has an information value of $R > 0$. Cohorts can be processed in isolation, since they are informationally independent.

An individual can learn an information item in two ways. He can 'process' the item directly, which takes $\tau > 0$ units of time per item. Working alone, an individual can thus generate a per period flow return of $R/(\tau M)$.

He can also learn it from other individuals through communication. But it takes time for an individual to learn what another member of the organization already knows, because of communication costs. It is simplest to think of those as 'reading costs'. Specifically, it takes $\tau(\lambda + am)$ for an individual to read a 'report' sent by any other individual which summarizes the content of m information items. $\tau\lambda > 0$ is thus a fixed setup cost per report, while $\tau a > 0$ is the variable cost of communication. The presence of $\tau\lambda$ means that there are increasing returns in communication. As will become clear, increasing returns in communication are a necessary condition for multiple rounds of communication. Moreover, $\lambda + a < 1$ is a necessary condition to have any communication at all.

The total time spent on each cohort by the organization includes processing and communication time. While the first is unavoidable, the second can be *eliminated* by having individuals work independently on separate cohorts and not communicate. Two separate reasons have been given for why agents communicate, when communication is costly: concerns for *delay* and returns from *specialization*.

[1] An alternative interpretation of information processing is assembling, taking a manufacturing perspective.

[2] M is exogenous, but this assumption could be relaxed. The information item is the basic unit here.

3. The firm's time constraint

3.1. Delay

Concerns for delay have mainly been emphasized in computer science. Their implication for the internal organization of firms have been pursued by Radner (1993) and Van Zandt (1990). [3] Delay is defined as the time interval between the moment at which the cohort 'arrives' and the moment it is fully processed. An individual working alone avoids communication costs altogether but incurs a delay of τM. Two individuals working together can split the processing activity among themselves and process a cohort in parallel, but one individual must then read the items processed by the other. If processing is divided equally, total delay is then $\tau(M/2) + \tau(\lambda + a(M/2))$, which is lower than τM if $\lambda + a(M/2) < (M/2)$. In this case, there is both a benefit and a cost of *parallel processing*: the benefit is reduction in delay, the cost is increased communication: while delay is reduced, the total time spent by the organization per cohort is $\tau M + \tau(\lambda + a(M/2))$, which is higher than the time spent by an individual working alone on a cohort.

Radner (1993) has analyzed the problem of the optimal design of an organization (called hereafter an 'optimal communication network' [4]) whose objective is to minimize delay in processing a single cohort in the special case when variable communication costs are zero (that is, $a = 0$). To be concrete, information items can, for example, be interpreted to be investment projects. Information processing then means learning the net present value (NPV) of the project. Suppose now that the organization can afford to invest only in a single project, and its problem is to select the best one with minimum delay. Assuming $a = 0$ makes sense here, since individuals' reports only contain a single project, the best one of the set of projects they know about, however large the set of projects is. [5]

Fig. 1 portrays an optimal communication network composed of four individuals. Assume for example $\tau = \lambda = 1$ and $M = 20$. In this network, all individuals first spend five periods processing individual items. In period 6, individuals 1 and 3 read individuals 2 and 4's reports respectively. Finally, in period 7, individual 1 reads individual 3's report. Radner (1993) shows this type of network to be optimal (in terms of minimizing delay) in general, up to integer constraints. [6]

Optimal networks involve two stages: first, the processing task is divided equally. Then, pairwise communication takes place. This network is far superior to the one portrayed in Fig. 2, where a 'superstructure' of individuals specializes in

[3] See Radner (1992) and Van Zandt (1994, 1995) for a detailed overview of the subject.

[4] The literature uses the word 'hierarchy' to describe some networks, even tough no relation of authority need exist between individuals.

[5] See also Van Zandt (1995) for a resource allocation problem where individuals' reports contain marginal cost curves.

[6] Which are avoided here because 20 can be divided by 4, and because 4 is a power of 2.

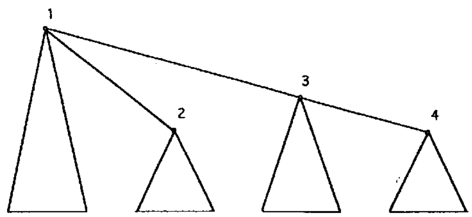

Fig. 1.

reading reports. Since they start 'from scratch', it takes individuals 5, 6 and 7 two periods each to do a job which was done in a single period before, bringing total delay to 9 periods even though 3 additional individuals work on the cohort.

There is one feature of the optimal network of Fig. 1 which does not seem consistent with real-world organizations: individual 1, at the 'top' of the network, is also involved at every stage of the processing and communication activities. This lack of specialization means in particular that individual 1 works for the full 7 periods of time it takes to process the cohort. In contrast, in Fig. 2, no individual works more than five periods.

This observation naturally leads one to conjecture that in environments where cohorts arrive repeatedly, optimal networks involve more specialization. While Radner (1993) provides a first look at this issue, Van Zandt (1990) characterizes optimal networks in a repeated stationary environment (also for $a = 0$). He shows however that optimal networks still look like in Fig. 1. The main difference is that in the stationary environment, there is rotation in the teams of individuals across cohorts, so as to equalize average individual workloads over time.

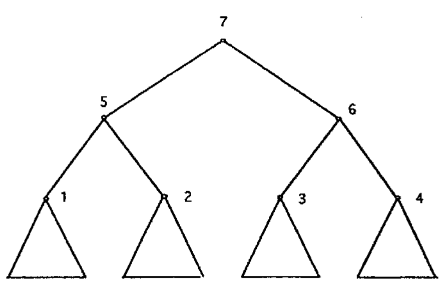

Fig. 2.

3.2. Gains from specialization

Assume the cohort to be an M-tuple of specific items $(n_1, n_2, \dots, n_M)$ which individuals manage to process or to read faster if they perform this activity more frequently (in the spirit of Adam Smith's pin factory). Specifically, assume that τ becomes $\tau(x)$ where x is the frequency of processing cohorts; then $\tau'(x) < 0$. Frequency is a single parameter, because we concentrate on fixed networks, without any rotation of tasks among individuals.

Henceforth, there is no concern for delay; instead the organization seeks to minimize total time spent per cohort. A single individual can achieve a frequency $x = (\tau(x)M)^{-1}$ [7]. Two individuals may achieve a higher frequency, but have to incur communication costs. Assume individual 1 processes m_1 items, while individual 2 processes the remainder $(M - m_1)$ items and reads 1's report (which takes time $\tau(x)(\lambda + am_1)$). Their workloads per cohort are $\tau(x)m_1$ and $\tau(x)(M - m_1 + \lambda + am_1)$ respectively. Since frequency is determined by the individual with the higher workload, we have $x = [\tau(x)\max\{m_1, M - m_1 + \lambda + am_1\}]^{-1}$. *Overall* time spent per cohort is $\tau(x)(M + \lambda + am_1)$. This means that individual 2's workload should never be lower than individual 1's. Alternatively, in order to cut communication costs, individual 2 should delegate tasks to individual 1 only in order to raise frequency. Also, individual 1's relative load will be higher the higher the returns from specialization. It will be determined by the comparison between these returns and the costs of communication. In Bolton and Dewatripont (1994), we determine the design of internal organizations under returns from specialization. This analysis generates the following insights:

(a) Since individuals should delegate only when overloaded, they tend to work *full time* even when the organization has to pay them only by the hour worked and no fixed hiring cost per worker is incurred.
(b) Individuals tend to have a *single superior*, that is, to send a single report, in order to cut fixed communication costs.
(c) Because of positive variable costs of communication, longer reports should reach the top of the network with fewer intermediate steps. Consequently, individuals tend to *specialize* across layers of the network, as in Fig. 2. Moreover, individuals at the bottom of the network only communicate with individuals in layers just above them. This approach thus throws some light on the process described by Chandler we referred to in the Introduction.

3.3. Summary

The two approaches described here are in our view very powerful, since they deliver strong predictions about network design in repeated environments which

[7] A solution to this equation exists if we assume $\tau(0) < \infty$ and $\tau(\infty) > 0$. If multiple solutions exist, one should obviously concentrate on the highest x.

are empirically plausible and do not depend on the size of the organization. In particular, they naturally lead to considerations about delegation or the specialization of communication channels.

Clearly, the framework considered here is extremely stylized and important dimensions of internal organizations have been ignored, such as the absence of uncertainty, heterogeneity among agents, training and promotion, etc. Needless to say, incentive issues, although absent from this framework, are highly relevant. Thus, future research ought to investigate all the above extensions and others. We expect that important principles of internal organization could be uncovered by pursuing these dimensions.

4. The firm's budget constraint

In Bolton and Dewatripont (1992), we investigate a capital budgeting application of the framework [8] developed above, as well as an alternative way of cutting communication costs: *decentralization* of decision-making, at the cost of lower information value per cohort. Decentralization is defined here as a decision to reduce coordination by treating independently subsets of the general optimization problem (and its associated cost). Instead, in Section 3, we have looked at how *delegation* tackles a *given* optimization problem, at the cost of *increased* communication costs, since more individuals are involved in information processing. Capital budgeting allows us to introduce the firm's budget constraint. Taking an imperfect capital market perspective, we assume that the organization has a fixed budget y per cohort. It also has a fixed number of specialized individuals it can rely upon to process individual investment projects or to compare projects that have been processed. This analysis generates the following tradeoff: more centralization means that more time is spent on allocating funds to identified investment opportunities, but less time on identifying new projects. This tradeoff favors centralization under tight budgets, but decentralization dominates otherwise.

To take an example, assume the firm can hire at most 3 individuals, at a wage w per period. 'Processing' a project means locating it and learning its NPV, which ex ante can be 0 or 1, with equal probabilities. Assume strong returns to specialization, so that individuals process only one project per cohort at the optimum. To avoid integer problems, set $\tau(1) = 1 = 2(\lambda + a)$, so that it takes one period to process one project, and half a period to communicate it. Now, consider in turn budget sizes of $y = 1, 2$ *or* 3.

[8] Capital budgeting often follows a hierarchical selection process (see Brealey and Myers, 1991, pp. 261–262).

Decentralization means here that individuals receive a fixed budget ex ante, of 1 per cohort, and are on their own. They then generate a net surplus $(0.5 - w)$ each in expected terms. With $y = 2$ or 3 and at most 3 individuals, such networks will be optimal, generating surpluses of $2(0.5 - w)$ and $3(0.5 - w)$ per cohort respectively. Indeed, specializing one individual in comparing projects would entail a cost w with no countervailing benefit if $y = 2$, while it would reduce investment opportunities with no countervailing benefit if $y = 3$. Instead, centralization may be optimal under tight budgets. If $y = 1$, the 'decentralized' option is to hire a single individual, who would generate a net surplus of $(0.5 - w)$ per cohort. Centralization involves two individuals processing one project each per cohort and a third individual selecting the better one for investment purposes. This solution generates a net surplus of $(0.75 - 3w)$, which is higher than $(0.5 - w)$ if $w < 0.125$. Instead, $(0.75 - 3w)$ is always worse than the decentralized solution for $y = 2$ for any nonnegative wage.

The more interesting comparison concerns $y = 1$ and $y = 3$: with a generous budget, every individual should be 'in the field', locating projects, instead of spending time reading about processed projects. Instead, with a tight budget, centralization is helpful in order to fine-tune investment choices. This approach thus generates an interesting interaction between the time and budget constraints of the firm, [9] which would be worth analyzing in a general context. [10] Also, this example sheds new light on the relative merits of centralization versus decentralization. Decentralization is better at uncovering new valuable investment opportunities, but centralization is better at resource allocation and coordination. These are important themes which ought to be investigated further and which cannot be taken up here at greater length for lack of space (and time!).

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[9] See Van Zandt (1995) for another rationale for decentralization, based on concerns for delay.

[10] See Bolton and Dewatripont (1992) for a start.

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