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TIME BASED COMPETITION
AND INNOVATION

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ABSTRACT

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Time Based Competition and Innovation[*]

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Abstract

By choosing their organizations, firms tradeoff productive efficiency and time spent at implementing innovation. We embed such a productivity/reactivity tradeoff in a growth model with creative destruction. We first highlight the specific impact of time in firm competition: in addition to weighing costs and benefits of late adoption, firms use time as a strategic variable through the possibility of overtaking their competitors. Due to this very specificity of time competition, multiple equilibria may emerge: when firms adopt quickly, their stockmarket valuation is larger, they innovate more and produce less. Moreover, IT revolution is shown to favor quick implementation via a general equilibrium feedback on organizational choice.

1. Introduction

It is widely felt among practitioners that firm reactivity to change matters today more than ever (Stalk [1988], Stalk and Weber [1993]). Consequently, emphasis has been put on "just in time" management methods, decentralization of decision making and speed of information transmission within the firm as necessary tools to improve performance. Why has time become such a scarce resource ? Organisation consultants and corporate executives have the vision that the pace of change in production technologies and product market conditions has accelerated in recent years[1]. In order to adapt to this increasing volatility, firms must innovate more frequently, and be able to implement innovations as quickly as possible. This phenomenon has been described in the business literature as "Time Based Competition".

It is indeed well known that innovation implementation is a time consuming process that depends heavily on organisational design. Well before economists, the sociological literature (Burns and Stalker [1961], Crozier [1965]) has emphasized two ideal types of

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[1]Such a view is held by Piore and Sabel [1984]. There is indeed some preliminary evidence that firm level uncertainty has risen over the past twenty years (see Comìn [1999], Thesmar and Thoenig [2000]).

organisation. decentralised, flexible firms, where informal, horizontal communication predominates have a comparative advantage at coping with the introduction of product or process innovation. Those firms rely on their workers' skills, and have often been compared to craftsmen workshops. On the other hand, large bureaucracies, where processes and information flows are routinized, where know how is embodied in rules and procedures, experience gains in efficiency but also difficulties to adapt to changes brought by innovations. This tradeoff between efficiency and reactivity has lately been emphasized in the economic literature. Aoki [1986] starts with the view that centralization of decision making allows to achieve optimal ressource allocation within the firm[2]. However, he posits that centralization takes time because it is associated to some form of learning. Radner [1993] and Bolton and Dewatripont [1994] have explicitly modeled this learning process. In doing so, they tackled the question of quickest information processing by a network of boundedly rational bureaucrats.

Hence, one important dimension of organisation choice is a tradeoff between productive efficiency and speed of innovation implementation. This suggests that time has to be considered as an input in the production process, and that how much time is invested on implementation depends on organisational design. Is time like any other input ? If not, what consequences does it have on competition and innovation ? These questions are addressed in this paper.

We start with the assumption that firms have to choose between being reactive (producing soon after innovation), or productive (producing later, but more efficiently). In this set-up, consumption of time increases future profit flows, but (1) acts as an opportunity cost of delaying production and (2) entails a risk of being overtaken by competitors. We show that if this threat of overtaking is not taken account of, the innovation process has no impact on the choice of time consumption. In other words, more frequent innovations disfavors time consumption in our set-up *because of the very specificity of time based competition* (the possibility of overtaking). We then endogenize innovation effort with a model of growth through creative destruction. We show that multiple equilibria may emerge. In the equilibrium where firms implement quickly, their stock market valuation is larger, they innovate more, and produce less. Finally, in such a set-up, increasing availability of fast information processing devices is complementary to the emergence of new organisations *even if IT does not affect organisation choice directly*. The intuition is that IT increases the efficiency of innovation implementation, and therefore stimulates innovation. Faster innovation then promotes organistic forms of organisations.

The contribution of this paper is twofold. Contributions emphasizing the role of time

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[2]See Demsetz [1997].

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in firms have focused on information processing within the firm, and the design of the optimal hierarchy (Bolton and Dewatripont [1994], Radner [1993]): they never crossed the boundaries of the firm. On the other hand, most traditional models of industrial organisation view firm competition as based on prices, capacity, or innovation. Our framework explicitly considers the strategic role of time in competition. In addition to raising the opportunity cost of not producing, delaying production increases the firm's exposure to being overtaken by quicker competitors. This very specificity of time based competition is responsible for the interaction between innovation and equilibrium time consumption decision, and for the emergence of multiple macroeconomic equilibria. Hence, we present a framework that helps to think about time competition and its interactions with innovation and growth. As far as we are aware of, no paper so far as tried to address this issue. Closest in spirit to our work are papers by Saint Paul [1993], and more recently, Comìn[1999], who analyze the interaction between firm level uncertainty and flexibility choices. They however do not deal with time competition and innovation.

The article is organised as follows. Section 2 is devoted to a presentation of the model. Section 3 takes the innovation process as given in order to highlight the two facets of time consumption: opportunity costs and overtaking expectations. We then solve for the equilibrium. Section 4 endogenizes innovation, and derives the general equilibrium effects of time based competition. Multiple equilibria emerge: we compare them, evaluate the effect in our set-up of a breakthrough in information processing technologies. Section 5 emphasizes the specific role of time in the preceeding results by re-solving the model without overtaking expectations.

2. The Model.

The framework presented below is based on the model of schumpeterian growth developed by Aghion and Howitt [1992] and Grossman-Helpman [1991].

Time is continuous. L is the total labour endowment of the economy, supplied inelastically at price w. A representative consumer optimises its intertemporal utility

$$U_T = \int_T^\infty \ln(C_t)e^{-\rho(t-T)}dt \tag{2.1}$$

where C_t is an index of consumption at date t, and ρ is the subjective rate of time preference. Financial markets are assumed to be perfect. If we define E_t as aggregate spending and r_t as the interest rate, straightforward dynamic utility maximisation yields: $\frac{\dot{E}_t}{E_t} = (r_t - \rho)$. We then normalise E_t to 1, which ensures that $\forall t$, $r_t = \rho$. The consumption index is a function of a continuum of goods $i \in [0; 1]$. These goods are subject to quality improvements through innovations. The consumption index as a function of the

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consumptions of the different goods and their respective qualities is given by:

$$\ln C_t = \int_0^1 \ln(\lambda^{s(i)}.c_t(i))di$$

where $\lambda > 1$, $s(i)$ denotes the number of innovations experienced by good i since the beginning of times, and $c_t(i)$ the quantity of i consumed at date t. Under this specification, demand addressed to sector i is given by :

$$x_t(i) = \frac{1}{p_t(i)} \tag{2.2}$$

In each sector, research labouratories produce innovations according to a Poisson process θ. In this activity, technology has constant returns: $\theta(i) = \frac{1}{b}.l(i)^{RD}$ where $l(i)^{RD}$ is the number of researchers searching for an innovation in sector i. Once found, patents are sold by labouratories to an infinity of potential final good producers; hence a successful lab can capture the whole value of the patent exploitation. We further assume that labouratories cannot direct innovations toward a specific sector i. This simplifies general equilibrium analysis, and allows us to focus on our main mechanisms.

In each sector i, risk neutral producers use labour according to a constant return technology $y = a_{\{m,o\}}.l$ where $a_{\{m,o\}}$ is the endogenous level of productivity (see below). Different patent owners in sector i compete in price to sell their good to the consumer. In equilibrium, as it is standard in this kind of literature, a single supplier is actually producing: the one with the largest quality price ratio. The unit cost function of a firm is given by:

$$C(a_{\{m,o\}}, w) = w/a_{\{m,o\}}. \tag{2.3}$$

Once the firm has bought the patent, the implementation of the production process is time consuming. For the duration of implementation, the firm cannot produce at all. Then, production takes place according to the technology described above.

Our starting assumption is that t is endogenous. Just after the purchase of the patent, we allow the firm to choose between a *mechanistic* organisation[3] m, and an *organistic* one o such that:

$$\begin{cases} t_o < t_m: \text{an organistic firm is more reactive.} \\ a_o < a_m: \text{a mechanistic firm is more efficient at producing.} \end{cases} \tag{2.4}$$

We thus assume that there is a tradeoff between producing more efficiently and reducing the delay of implementation[4]. This view of organisation was first emphasized by Aoki

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[3] We borrow this terminology from sociologists Burns and Stalker [1962].

[4] Firms are assumed to have no capacity constraints: hence, a slow incumbent can be completely crowded out by a quicker entrant. This makes time competition most stringent.

(1986). Following Coase (1937), he argues that a centralised organisation accounts for the externalities between different production units within firm, because it allows firm to coordinate the optimal allocation of ressources. Thus centralization increases efficiency. On the other hand, as shown by Radner (1993) and Bolton and Dewatripont (1994), the very act of collecting and centralizing information by bounded rational agents consumes time. Consequently, implementation of innovation requires more delay in a centralised organisation than in a decentralised one, but it will be done more efficiently.

The efficiency/reactivity tradeoff (2.4) is discrete. This assumption simplifies greatly the formal analysis, but it can be grounded on recent economic research on firm organisation, which shows empirically that organisational practices tend to be adopted in clusters (Ischniowsky and Shaw [1995]). According to Milgrom and Roberts (1990), the theoretical reason for this would be that they are strongly complementary with each other, and with the adoption of new technologies[5].

Finally, we assume that organisation choice is *irreversible*. A firm cannot decide to be first organistic (produce soon), and then mechanistic (be efficient). We justify this irreversibility in two ways. First, this hypothesis is realistic and supported by the fact that firms do not change organisation very often. Second, work organisation can be viewed as a nexus of implicit contracts between the managers and the workers. The working of these contracts is deeply tied to the current organisation (job definition, negociated career plans, continuous training). A reorganisation would cause the breakdown of existing rules, and would require the creation of new ones and a strong managerial commitment to them, which we assume too costly.

3. Innovation and Time Competition.

As a first step before general equilibrium analysis, we study a firm's incentive to choose one type of organisation when environmental change is exogenous: hence, we take the rate of creative destruction θ as given. In this section, we highlight the overtaking effect, which is the possibility for an uptodate organistic firm to produce before a mechanistic incumbent[6]. As a result, when environment becomes turbulent, firms are compelled to choose to be organistic in order to avoid being overtaken by others.

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[5]In Milgrom and Roberts's [1990] phrase: "A striking feature of the discussions of flexible manufacturing found in the business press is the frequency with which it is asserted that successful moves toward "the factory of the future" are not a matter of small adjustments made independently at each of several margins, but rather have involved substantial and closely coordinated changes in a whole range of the firm's activities"

[6]Hereafter, we will call an *incumbent* a firm which is implementing whereas the producer is a firm which has finished the implementation process and has the monopoly on the market.

3.1. State Space

In what follows, we consider only one sector, and thus unambiguously omit the sector subscript i. At date τ, a given firm buys the patent and must choose its organisation . It observes a firm that is currently selling an input of quality λ_0 discovered at date τ_0, and incumbents that are not producing yet, but still developing a production process with an organisation that is either mechanistic or organistic. We index these incumbents by their rank of apparition i, starting with 1 for the oldest one. We denote by (τ_i, a_i) the date of the patent purchase and the choice of organisation of firm i. Hence, we define the *relevant* past history as the sequence of organisational choices and dates of patent purchases of all incumbents at τ, and that of the actual producer (τ_0, a_0): $\Omega_\tau = \{(\tau_0, a_0), ..., (\tau_j, a_j), ..., (\tau_n, a_n)\}$ is thus the state variable of our dynamic system.

3.2. Profit Function

Consider a Bertrand competition between a producer achieving a quality $\hat{\lambda}$, and another firm achieving $\hat{\lambda}.\lambda^{n+1}$ (the newcomer, that is $n+1$ quality steps ahead). Because of the unit elasticity of demand (equation (2.2)), the newcomer will be able to charge slightly less than $p = \lambda^{n+1}.\hat{c}$ where $\hat{c}$ is the cost production of the producer, crowding it out of the market. Profits are given by: $\pi = (p-c).x$ where c is the unit cost of the best quality firm and where x is output. From (2.2) we get $\pi = 1 - c/\hat{c}$. With (2.3) we can express the firm's profit function as:

$$\pi_{\hat{a},a,n} = 1 - \frac{\hat{a}_{\{m,o\}}}{\lambda^{n+1}.a_{\{m,o\}}} \tag{3.1}$$

where $\widehat{a}_{\{o,m\}}$ is the producer's productivity, and $a_{\{o,m\}}$ the newcomer's one.

Equation (3.1) highlights the two potential sources of profit of a firm. It depends on its organisation choice relative to the producer $(\widehat{a}/a)$ and its quality advance (n).

3.3. Overtaking.

A patent owner is said to be overtaken if, before begining to produce, a more uptodate innovator begins to sell its product. An example of this is displayed in figure I. Once firm A has chosen to be mechanistic (low reactivity) at τ_a, there is a positive probability that the next innovation is found at $\tau_b = \tau_a + \varepsilon$, where $\varepsilon < t_m - t_o$. Assume now that the next patent buyer (firm B) decides to be organistic. Its quality price ratio will be lower than firm A's if $\frac{\lambda}{p_B} < \frac{1}{p_A}$. Firm B's unit cost is w/a_o. Firm A's unit cost is w/a_m. Hence, if $\frac{a_m}{a_o} < \lambda$, firm B will have a higher quality price ratio than A, and, since $\tau_b + t_o < \tau_a + t_m$, it will be able to start producing sooner. Thus, A will never be able to sell its products.

Hereafter, we make the following two assumptions

$$\frac{a_m}{a_o} \quad \ll \quad \lambda \qquad\qquad (A1)$$

$$r(t_m - t_o) \quad \ll \quad 1 \qquad\qquad (A2)$$

Assumptions (A1) and (A2) imply that both types of organisations are not too different from each other when compared to macro variables. (A1) states that the productivity differential between a mechanistic and an organistic firm is small when compared to the quality improvement brought by an innovation. (A2) implies that lost profits from late technology adoption are not too different from foregone profits of early adoption.

None of these assumptions is necessary for the results, but we made them in order to emphasize the overtaking mechanism, which we believe is the very specificity of time based competition in this set-up. Hence, the gains of overtaking, as well as losses from being overtaken, will be the principal driving forces governing equilibria in the subsequent analysis.
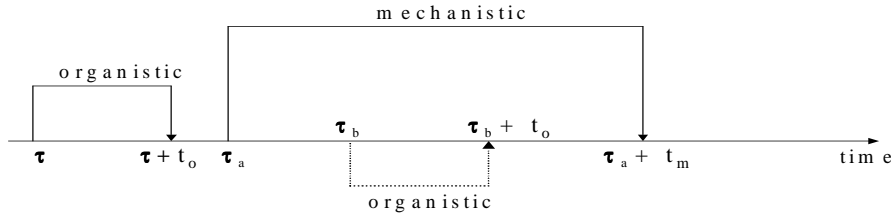

Figure I : Example of Overtaking

3.4. Equilibrium Definition.

A firm's strategy, $a(.)$, is a mapping from the set of possible histories $\{\Omega_\tau\}$ to the set of action $\{a_o, a_m\}$. Organisation choice depends on the past history Ω_τ for two reasons: first, since Bertrand competition the firm's productivity choice depends on the other firms' productivity -this corresponds to the fact that $\hat{a}$ appears in equation (3.1). Second, the firm may choose to be reactive enough in order to overtake as many non producing incumbents as possible -the higher n the higher is the profit in equation (3.1).

Equilibrium defines the way a given firm chooses one's strategy while taking the others' strategies as given. As firms play sequentially, the relevant equilibrium concept here is a subgame perfect equilibrium. As the horizon is infinite, we use the definition provided by VanDamme [1991]. The equilibrium definition goes as follows: the firm's sum of expected

profits depends on past history Ω_t and the other palyers' future strategies $a_{-1} = \{a_j(.) : \Omega_{t'} \rightarrow \{a_o, a_m\} | t > t', \ j \neq i\}$. For each history Ω_t, the firm therefore has an optimal response $\alpha = A(\Omega_t, a_{-1})$, which defines, for all given strategies, a function of past history (therefore a best strategy, or reaction function). The intersection of all reaction functions is a subgame perfect Nash equilibrium.

From the Folk theorem, we know that the set of equilibria is likely to be large. We are nevertheless in a position to derive existence conditions for simple types of symmetric equilibria. Hereafter, we will therefore look for a mechanistic equilibrium (where $a(\Omega_t) = a_m$, $\forall \Omega_t$) and for an organistic equilibrium (where $a(\Omega_t) = a_o$, $\forall \Omega_t$).

3.5. Organistic Equilibrium

We study here the existence conditions of an organistic equilibrium: $a(\Omega_t) = a_o$, $\forall \Omega_t$. To proceed, we use the "one-shot deviation principle" which states that playing a_o is an equilibrium in every subgame (ie. for each Ω_τ) if no player , whenever it is his turn to move, has an incentive to choose a different action (ie. playing a_m).

In the following proposition, we show that such equilibrium always exists as long as θ is large enough:

Proposition 1 *Repeated organistic choice is a subgame perfect equilibrium if and only if $\theta \geq \theta^*$, where:*

$$\theta^* \equiv \frac{(a_m/a_o) - 1}{\lambda.(t_m - t_o)} - r$$

Proof: Let us assume that the equilibrium strategy is given by $a^*(\Omega_\tau) = a_o$. We are looking for necessary and sufficient condition on θ such that no firm will deviate from this strategy whatever Ω_τ.

What are the histories $\tilde{\Omega}$ for which a firm has the strongest incentive to deviate from $a^*(.)$ and thus play a_m? As all future producers play the equilibrium strategy $a^*(.)$, they are expected to be organistic. Hence, the benefit of playing organistic consists in overtaking mechanistic incumbents. The benefit of playing mechanistic consists in having a high productivity a_m parameter compared to its incumbents. Hence, the situation where the benefits of being mechanistic (resp. organistic) are the highest (resp. the lowest) is a situation where overtaking is not possible. Thus $\tilde{\Omega}$ are histories where there is one producing firm and no incumbent: if the producer is organistic (resp. mechanistic), we refer to the history as being $\tilde{\Omega}_o$ (resp. $\tilde{\Omega}_m$).

- Case $\tilde{\Omega}_o$:

As stated above, in this configuration, the firm cannot overtake any incumbent: it competes only with the organistic producer (see figure II). Profits are given by (3.1): π_{oo} (resp. π_{om}) is the profit if the firm chooses to be organistic (resp. mechanistic) and $\pi_{oo} = 1 - \lambda^{-1}$, $\pi_{om} = 1 - (a_o/a_m)\lambda^{-1}$. If we denote by η the date at which the firm will be outperformed by a more uptodate innovator, the values of an organistic and a mechanistic firm are given by $V_{oo} = \underset{\eta}{E} \left[\int_{t_o}^{\eta} e^{-r.s}.\pi_{oo}.ds \right]$ and $V_{om} = \underset{\eta}{E} \left[1_{\{\eta \geq t_m\}} . \int_{t_m}^{\eta} e^{-r.s}.\pi_{om}.ds \right]$. The indicator function $1_{\{\eta \geq t_m\}}$ takes account of the fact that a mechanistic firm can be overtaken by future reactive innovators.

As θ is an exogeneous Poisson process, straightforward calculations yield:

$$V_{oo} = \underbrace{e^{-t_o.r}}_{II'} \cdot \underbrace{\frac{1}{r+\theta}}_{III'} \cdot \underbrace{\pi_{oo}}_{IV'} \tag{3.2}$$

$$V_{om} = \Pr(\eta \geq t_m).E[\int_{t_o}^{\eta} e^{-r.s}.\pi_{om}.ds] \tag{3.3}$$

$$= \underbrace{e^{-(t_m-t_o).\theta}}_{I} \cdot \underbrace{e^{-t_m.r}}_{II} \cdot \underbrace{\frac{1}{r+\theta}}_{III} \cdot \underbrace{\pi_{om}}_{IV} \tag{3.4}$$

Consequently, the firm is not tempted to deviate from the equilibrium strategy $a^*(.)$ if: $V_{oo} > V_{om}$. It means:

$$e^{(t_m-t_o)(r+\theta)} > (\lambda - a_o/a_m)/(\lambda - 1) \tag{3.5}$$

- Case $\tilde{\Omega}_m$:

In this configuration, the firm competes against a mechanistic producer. The reasoning is similar to the former case and we can show that the firm is not tempted to deviate from the equilibrium strategy $a^*(.)$ if:

$$e^{(t_m-t_o)(r+\theta)} > (\lambda - 1)/(\lambda - a_m/a_o) \tag{3.6}$$

A straightforward computation shows that (3.5) is always true when (3.6) is true. Hence, a firm always follows the equilibrium strategy $a^*(.)$ (ie. playing a_o in every history Ω_τ) if and only if (3.6) is satisfied, which means:

$$\theta \geq \frac{\ln((\lambda - 1)/(\lambda - a_m/a_o))}{t_m - t_o} - r \tag{3.7}$$

Provided assumption (A1) holds, the condition (3.7) boils down to[7]:

$$\theta \geq \frac{(a_m/a_o) - 1}{\lambda.(t_m - t_o)} - r \equiv \theta^*$$
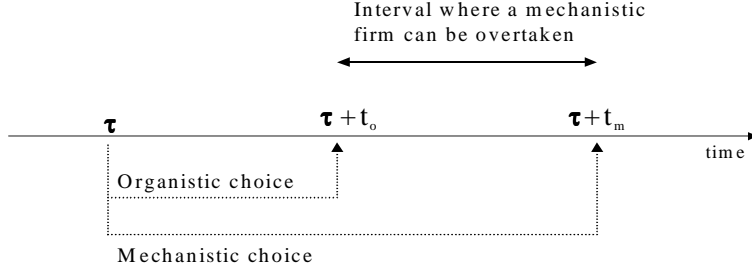
Q.E.D

Figure II: organistic equilibrium

The intuition of proposition 1 is the following. Expressions (3.2-3.4) tell us that in an environment where all other firms choose to be organistic, a mechanistic firm takes advantage of its higher productivity to increase profit in Bertrand competition ($IV \succ IV'$). On the other hand, its opportunity cost of delaying production is higher ($II' \succ II$), and overtaking threat is active between τ and $\tau + t_m - t_o$, which lowers its expected value ($I \prec 1$). As the rate of creative destruction raises, the threat of being overtaken becomes the dominant effect (I goes down). Thus, higher levels of activity in the research and development compell firms to choose more reactive organisations.

3.6. Mechanistic Equilibrium

In this section, we provide condition of the existence of a mechanistic equilibrium.

Proposition 2 *Repeated mechanistic choice is a subgame perfect equilibrium if and only if $\theta \leq \theta^*$.*

Proof: The reasoning still uses the "one-shot deviation principle". Let us assume that the equilibrium strategy is given by $a^*(\Omega_\tau) = a_m$. We are looking for necessary and sufficient conditions on θ such that no firm will deviate from this strategy whatever Ω_τ.

What are the histories $\tilde{\Omega}_\tau$ for which a firm has the strongest incentive to deviate from $a^*(.)$ and thus play a_o? As the sole benefit of being organistic consists in overtaking

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[7]Indeed:

$$\ln\left(\frac{\lambda - 1}{\lambda - a_m/a_o}\right) = \ln\left(1 + \frac{a_m/a_o - 1}{\lambda - a_m/a_o}\right) \simeq \ln\left(1 + \frac{a_m/a_o - 1}{\lambda}\right) \simeq \frac{a_m/a_o - 1}{\lambda}$$

mechanistic incumbent, it is straightforward that the histories $\tilde{\Omega}_\tau$ correspond to the cases *where all the incumbents are mechanistic* (see figure III). Indeed, if the firm manages to buy an innovation shortly after the last patent was issued, it may be able to overtake the last incumbent and thus earn higher profits, because its quality improvement with respect to the current producer will be λ^2 instead of λ for a short period.

Consider such a history $\tilde{\Omega}_\tau$. We denote V_{mm} and V_{mo} the expected cash-flow of a mechanistic (resp. organistic) firm in this mechanistic environment. V_{mm} does not depend on the past innovation timing, but V_{mo} does. Thus, if the firm is in position to overtake enough previous incumbents, these gains can outweigh the loss from being less productive than them (see equation (3.1)).

This "aggressive" behavior is the main difference with the preceeding section.

- From figure III, we can see that if the firm chooses a mechanistic organisation then the cash-flow is independent of the past sequence of innovation (it can not overtake any of the incumbents):

$$V_{mm} = e^{-t_{\mathrm{m}}.r} \frac{\pi_{mm}}{r+\theta} \text{ with } \pi_{mm} = 1 - \lambda^{-1} \tag{3.8}$$

- If the firm decides to be organistic, we have:

$$V_{mo}(\tilde{\Omega}_\tau) = \underset{\eta}{E} \left[\int_{\tau+t_{\mathrm{o}}}^{\tau_1+t_m} e^{-rs}.\pi_{mo}^n.ds + \int_{\tau_1+t_{\mathrm{m}}}^{\tau_2+t_m} e^{-rs}.\pi_{mo}^{n-1}.ds + ... + \int_{\tau_{\mathrm{n}}+t_{\mathrm{m}}}^{\eta} e^{-rs}.\pi_{mo}.ds \right] \tag{3.9}$$

The payoff $V_{mo}(\tilde{\Omega}_\tau)$ depends of the sequence of incumbents $(\tau_1, ..., \tau_n)$. The more $(\tau_1, ..., \tau_n)$ is "peaked" around τ_1 the bigger is the value $V_{mo}(\tilde{\Omega}_\tau)$, but the probability of such an event is closer and closer to 0. Intuitively, the event $\tilde{\Omega}$ that is the most favorable to becoming organistic occurs when an infinity of mechanistic incumbents bought patents just before the firm does. Parameters verifying $V_{mo}(\tilde{\Omega}) \le V_{mm}$ are such that becoming mechanistic for all Ω_τ is optimal: there is no deviation from the equilibrium.

More formally, let us call $\tilde{\Omega}_\tau^{n+1}$ the event $\{\tau_1 = \tau_2 = ... = \tau_n = \tau\}$ which corresponds to $(n+1)$ innovations found at the same moment. Although such an event has a probability 0, it is a limit case. The value of an organistic firm facing this event is:

$$\tilde{V}_{mo}^{n+1} = \underbrace{\int_{t_{\mathrm{o}}}^{t_m} e^{-rs}.\pi_{mo}^{n+1}.ds}_{\text{overtaking benefits}} + \underset{\eta}{E} \left[\int_{t_{\mathrm{m}}}^{\eta} e^{-rs}.\pi_{mo}.ds \right] \tag{3.10}$$

Computations show that:

$$\tilde{V}_{mo}^{n+1}(\theta) = \frac{e^{-t_{\mathrm{o}}.r} - e^{-t_{\mathrm{m}}.r}}{r}.(1 - \frac{a_o}{\lambda^{n+1}.a_m}) + e^{-t_{\mathrm{m}}.r}.\frac{\pi_{mo}}{r+\theta} \tag{3.11}$$

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Thus $\tilde{V}_{mo}^{n+1}(\theta)$ increases with n (more incumbents to overtake) and decreases with θ (innovation rate).

Hence, the firm is never tempted to deviate if: $V_{mm}(\theta) > \tilde{V}_{mo}^{n+1}(\theta)$ for every n. The continuity of equation (3.9) with respect to $(\tau_1, ..., \tau_n)$ guaranties that this condition is equivalent to:

$$\lim_{n \to \infty} \tilde{V}_{mo}^n \leq V_{mm}(\theta) \tag{3.12}$$

Taking the limit in (3.11) and using (3.8), we get that the condition (3.12) is equivalent to:

$$\theta \leq r. \left[\frac{a_m/a_o - 1}{\lambda.(e^{(t_m - t_o).r} - 1)} - 1 \right] \tag{3.13}$$

At this step, it is useful to consider that the interest rate r is close to 0. Consequently, the condition (3.13) is equivalent to:

$$\theta \geq \frac{(a_m/a_o) - 1}{\lambda.(t_m - t_o)} - r \equiv \theta^* $$
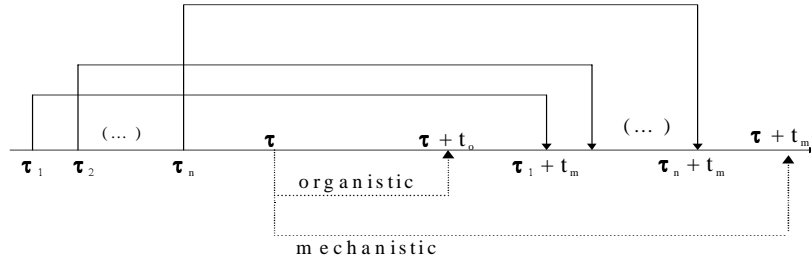
Q.E.D

Figure III: Mechanistic Equilibrium

Equations (3.8-3.10) embody the tradeoff between being organistic and being mechanistic here. On the one hand, Bertrand competition compels the firm to have a productivity advantage against incumbents in order to enjoy higher instantaneous profits ($\pi_{mo} < \pi_{mm}$). But on the other hand, a mechanistic firm incurs an opportunity cost of delaying production. In addition, if the past innovation sequence is favorable, the firm may be willing to become more reactive and to overtake its competitors (there is a number of incumbents, n, such that $\pi_{mo}^n \gg \pi_{mm}$). In a mechanistic environment (see figure III), if the previous incumbents are sufficiently "grouped" around τ, the firm may decide to overtake them and then make with certainty a profit equal to $\pi_{mo}^n > \pi_{mm}$ during period $(t_m - t_o)$. After this, the profit becomes $\pi_{mo} < \pi_{mm}$ only, until death. An increase in

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θ implies that the second time interval becomes in average shorter, which improves the comparative advantage of an organistic firm; on the contrary, a decrease in θ raises the relative size of the second period with respect to the first one.

The overtaking effect is once again at work in the mechanistic environment, but it acts in the opposite direction. Here the incentive to overtake (and not the threat of being overtaken) is determinant.

All in all, we have found that, for all θ, there always exists a subgame perfect equilibrium where all firms choose the same organisation. We now embed this sectoral result in the growth framework.

4. General Equilibrium Effects of Time Competition

In this section, we endogenize the rate of creative destruction θ: This helps us analyzing the feedback effect of time based competition on the aggregate rate of growth.

4.1. General equilibrium

As research labs cannot direct their research effort toward a given sector i, θ is the same in all sector. This ensures that the equilibrium will be the same in all sectors.

Since potential innovation buyers compete *à la* Bertrand to buy the patent, its price is exactly the value of the firm. We get from (3.2-3.8):

$$V_{\{o,m\}}(\theta) = (1 - \frac{1}{\lambda})\frac{e^{-r.t_{\{o,m\}}}}{r + \theta} \tag{4.1}$$

$$\text{where } t_{\{o,m\}} = t_m \text{ if } \theta < \theta^* \text{ and } t_{\{o,m\}} = t_o \text{ if } \theta > \theta^* \tag{4.2}$$

$$\text{with } \theta^* \equiv \frac{(a_m/a_o) - 1}{\lambda.(t_m - t_o)} - r \tag{4.3}$$

Note that this value function depends on the firm's organisational choices through the delay $\{t_o, t_m\}$ and not through the firms' productivity levels $\{a_o, a_m\}$. This stems from our assumption of Bertrand competition at the sectorial level where only relative productivities matter (cf. profit equation (3.1)); in this kind of competition a lower equilibrium productivity does thus not translate into lower profits. Consequently, the value of a patent is unambiguously larger in the organistic equilibrium than in the mechanistic one (for a given θ).

Free entry in R&D equalises the costs and benefits of the activity, thus:

$$bw = V_{\{o,m\}}(\theta) \tag{4.4}$$

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In each sector i, we know that the monopoly price is given by $p_i = \lambda w / a_{\{o,m\}}$. As demand for good i is $x_i = 1/p_i$, by aggregating over the continuum of goods we get the agregate labour demand in manufacturing $D_l = 1/(\lambda w)$. labour demand in R&D is $D_l^{R\&D} = b\theta$. Consequently, labour market clearing condition can be expressed as:

$$L = b\theta + \frac{1}{\lambda w} \tag{4.5}$$

Using equations (4.1-4.4-4.5), general equilibrium is obtained by:

$$L = b\theta + \frac{b(r+\theta)}{\lambda - 1} . e^{rt_{\{o,m\}}} \tag{4.6}$$

The labour demand (the RHS of this equation) is not monotonous, since above θ^*, firms change their time consumption, which increases the value of research, and therefore the demand for labour. This non-monotonicity may generate multiple equilibria, as shown in figure IV, and more formally in the proposition below.

Proposition 3 *(Description of Equilibria) There exists $(\underline{L}, \bar{L})$ such that:*

  1. if $L \leq \underline{L}$ then Industry is mechanistic in all sectors

  2. if $L \geq \bar{L}$ then Industry is organistic.

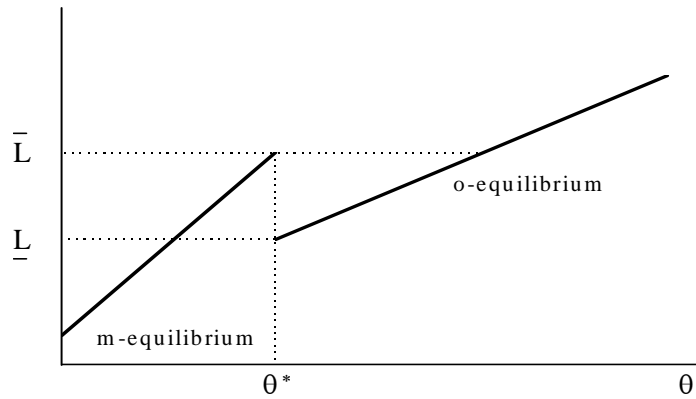 *3. if $\underline{L} \leq L \leq \bar{L}$ then Industry can be either mechanistic or organistic.*

Figure IV: Labor Demand

Proof.

  If we look at equation (4.6), we easily get that an organistic equilibrium is sustainable iff $\theta \geq \theta^*$. This inequality can be rewritten as: $L > \underline{L} \equiv b\theta^* + \frac{b(r+\theta^*)}{\lambda-1} e^{rt_o}$. A mechanistic equilibrium is sustainable iff $\theta \leq \theta^*$, or $L < \bar{L} \equiv b\theta^* + \frac{b(r+\theta^*)}{\lambda-1} e^{rt_m}$. We then get straightforwardly that $\underline{L} < \bar{L}$.

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Q.E.D

The above proposition states that, for intermediary sizes of the skilled labour force, the model can still generate multiple equilibria at the macroeconomic level. This result highlights the key role of a strategic complementarity that arises in general equilibrium, through the research and development sector. Indeed, let all other firms choose to be organistic. As noticed above, this common strategy raises their value, and thus the research and development's marginal productivity (recall that the labs' expected flow of profit is given[8] by $(V/b).l^{RD}$), which in turn raises its output, the growth rate θ. But from the preceeding section, we know that a higher rate of creative-destruction may render active the threat of being overtaken, and thus increases the comparative advantage of the organistic organisation .

In summary, the externality that firms' organisational decisions play on research and development and the feedback effect of innovation on both organisations' comparative advantages combine in a macroeconomic strategic complementarity that is responsible for the coexistence of a mechanistic and a organistic equilibria at the macro level.

4.2. Comparative statics

In this section, we aim at comparing the two equilibria. In order to do this, we compare the features of both equilibria for a given $L \in [\underline{L}; \bar{L}]$. We denote by a susbscript o (resp. m) the characteristics of the organistic (resp. mechanistic) equilibrium, and present comparative statics results for growth, production level and real wage.

Result 1 *The rate of creative destruction is larger in the organistic equilibrium: $\theta_o > \theta_m$. So is the firms' stock market values: $V_o > V_m$.*

Proof. The equilibrium rate of creative destruction, θ, is given by equation (4.6):

$$\theta = \frac{(\lambda - 1).L/b - re^{rt_{\{o,m\}}}}{\lambda - 1 + e^{rt_{\{o,m\}}}} \tag{4.7}$$

This equation directly drives the results.Q.E.D.

As discussed above, for a given θ, project values are higher if firms are organistic than if they are mechanistic because innovations are implemented more quickly in an organistic environment. This raises research and development's productivity, and its demand for labour and hence θ. In other words, firms' reorganisations by increasing the price of patents, tend to create a bias toward R&D activity and growth. As a result, more labour is devoted to innovation than to production.

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[8]Note that this effect is robust to a decreasing return to scale specification of the research and development technology: $\theta = \frac{l^\alpha}{b}$. As a consequence, all what follows remains valid under this alternative specification.

Result 2 *The production level is lower in the organistic equilibrium:* $X_o < X_m$.

Indeed, the output flow X is equal to $a_{\{o,m\}}.(L-b\theta)$ where the second term corresponds to the labour employed in manufacturing. Using (4.7) we have:

$$X_{\{o,m\}} = \underbrace{a_{\{o,m\}}}_{I} \cdot \underbrace{\frac{L+rb}{(\lambda-1)e^{-rt_{\{o,m\}}}+1}}_{II} \tag{4.8}$$

a is smaller in the organistic equilibrium (I). More ressources are devoted to research, such that the production level is also lower (II).

As outlined above, firms' reorganisations raise research and development's demand for labour , while leaving the industrial sector's unchanged. At the same time, firms' reorganisation reduces productivity $(a_o < a_m)$. Hence, the production flow is unambiguously lower in the organistic equilibrium for two reasons: first the firm's productivity goes down (I). Secondly, R&D becomes comparatively more productive, attracting more workers (II), which leaves less workers to the productive sector.

4.3. IT Revolution and Organisation Change: a Macro-Founded Complementarity

There is a growing empirical literature documenting the complementarity between adoption of new technologies (computers, communication devices) and the adoption of new forms of organisations (e.g. Brynjolfsson and Hitt [2000]). At the firm level indeed, it seems that productivity gains from new technology adoption require a change in workplace organisation to be fully efficient[9]. Hence, according to these authors, new organisational forms are complementary to new technologies *because* this was precisely the purpose they were designed for.

Such a view surprinsingly ignores the fact that the emergence of these organisations in many ways *precedes* the widespread diffusion of new technologies in the workplace (for example in Japan). Our model allows us to dispense from the ad hoc assumption that IT promotes organistic organisations against mechanistic ones, and show that new technologies nonetheless have effects on organization change through macroeconomic mechanism.

We will show that in our framework the IT revolution can compell firms to reorganise, *even if it does not directly affect the organisation choice itself* at the microeconomic level (i.e. it equally favors the efficiency of mechanistic and organistic organisations). The intuition is that, by increasing efficiency in both types of organisations, IT promotes

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[9] **This view has been widely shared by economic historians such as Paul David, who argued for example that Taylorism could never have emerged without the invention of electricity (David [1990]).**

innovation, which in turn promotes organistic firms. Time becomes more coslty, which makes it worthwhile to adopt more reactive organisations. Hence, IT revolution favors organistic firms via a general equilibrium effect.

We consider the case where initially $L < \underline{L}$, such that the equilibrium is initialy mechanistic. Given the improvements it brought in computer science and in telecomunications, the IT revolution can be argued to have dramatically reduced the time required to process a given amount of information. IT therefore is assumed to reduce the time necessary to implement an innovation for both organisations:

$$\left\{ \begin{array}{l} t_m \xrightarrow{IT} t_m - \delta \\ t_o \xrightarrow{IT} t_o - \delta \end{array} \right. .$$

A look at equation (4.3) shows that a reduction of processing time by δ does not change the threshold θ^*. In this model, IT does not affect the tradeoffs behind organization choice, because it has the same effect on the efficiency of both types of organisation.

IT does however induce an increase in the rate of innovation θ for a given supply labour L in both equilibria, because it acts as a positive productivity shock, that increases the values of both kinds of firms by a factor $e^{\delta r}$ (cf. equation 4.6). This makes research more attractive: the resulting increase in θ favors the organistic equilibrium.

5. Specificities of Time Based Competition.

So far, we have discussed some micro and macro implications of time based competition. We have highlighted the strategic complementarities at work, and shown that they may lead to multiple equilibria. It is not clear, however, whether these results depend on the specific role that time plays in this setup, or whether they could be obtained by replacing time by another input such as, say, final good. This section adresses this issue.

As we have shown in section 3, time plays two roles in defining the equilibrium at the sectoral level. First it acts like an opportunity cost: a larger delay of implementation reduces the expected return from an innovation. Secondly, time gives rise to *overtaking expectations*: firms need to pay attention to the risk of being overtaken by quicker competitors and to consider the opportunity of overtaking slower ones. These two facets of time based competition shape the equilibrium. However, while the latter is specific to our problem, the former could be modelled differently, through a sunk cost for example (see Thesmar and Thoenig [2000]).

The specificity of time in this set up can thus be highlighted by removing overtaking expectations from our model, and looking at the differences with the previous results.

Hence, consider the benchmark case where firms do not consider the threat nor the opportunity of overtaking[10]. At the sectoral level, the *organistic* equilibrium will be sustainable whenever:

$$\frac{1}{r+\theta}e^{-r\tau_o}(1-\frac{1}{\lambda}) > \frac{1}{r+\theta}e^{-r\tau_m}(1-\frac{a_o}{\lambda a_m}) \qquad (5.1)$$

while the mechanistic equilibrium obtains if:

$$\frac{1}{r+\theta}e^{-r\tau_m}(1-\frac{1}{\lambda}) > \frac{1}{r+\theta}e^{-r\tau_o}(1-\frac{a_m}{\lambda a_o}) \qquad (5.2)$$

In this case, firms just weigh the costs of waiting longer against the benefits of entering the market with a higher productivity: losing time acts here as a pure opportunity cost. As is clear from (5.1- 5.2), terms in $1/(r+\theta)$ cancel out. Hence, at the microeconomic level, equilibrium does not depend on θ. In economic terms, innovation affects discounting of profits for both choices, such that it has no effect on the tradeoff. *There is no interaction between the equilibrium speed of innovation implementation and the process of creative destruction.*

Let us now consider the case where, in the absence of overtaking expectations, the mechanistic equilibrium is the only one that is sustainable[11]. In this case, the aggregate research effort solves:

$$L = b\theta + \frac{b(r+\theta)}{(\lambda-1)}e^{rt_m}$$

The equilibrium is uniquely defined, both at the microlevel (by assumption), and at the macroeconomic level. This second feature results from the fact that θ has no impact on the sectoral equilibrium, and thus on the value of each patent. Hence, the macroeconomic complementarity that was emphasized in the above section disappears once we remove overtaking expectations.

In this set-up, overtaking expectations, which are specific to considering time as an input renders the organistic equilibrium more likely at the micro level, because it allows for an interaction between schumpeterian dynamics and organisation choice. If θ is large enough, overtaking threat deters firms from becoming mechanistic. Since the impact of θ on the sectorial equilibrium is at the core of the macro-complementarity highlighted in the previous section, multiple equilibria at the macroeconomic level cease to appear once one stops accounting for overtaking expectations.

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[10]It means that firms consider the delay of implementation only as an opportunity cost.

[11]This is the case when : $e^{r(t_m-t_o)} > (\lambda-1)/(\lambda-a_m/a_o)$

6. Conclusion

This paper is a first attempt at introducing time based competition, at assessing its specificity, and at investigating its potential impact on growth. We show that time plays two roles. The first one is standard: time consumption acts as an opportunity cost. The second one is the strategic opportunity/threat of overtaking. These overtaking expectations are responsible for the interaction between the schumpeterian process of creative destruction and the organisational equilibrium. This interaction can in turn generate multiple equilibria at the macroeconomic level.

An interesting extension would be to consider a growth model where incumbents innovate[12]. In this case, organisation choice affects all future innovation implementations of the firm. Implementation time/efficiency tradeoff can however be changed, at the expense of a sunk cost. Such a framework would allow to check the robustness of our overtaking effect, as well as to consider the circumstances and macroeconomic consequences of organisation change

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[12]Like the framework used by Aghion, Dewatripont and Rey [1999] to adress another issue.

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