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ON THE RELATION BETWEEN ORGANISATIONAL PRACTICES AND NEW TECHNOLOGIES: THE ROLE OF (TIME BASED) COMPETITION*

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This article studies some aspects of organisation choice while explicitly accounting for the fact that firms compete on the product market. Firms compete by introducing drastic innovations, while organisation choice results from a tradeoff between productive efficiency and reactivity. We show that the adoption of information technologies and the choice of reactive organisations are complements via an industry-level equilibrium effect. This view contrasts with the existing literature which emphasises the existence of similar complementarities *at the firm level.* Consistently with our model, we find that industry-level, rather than firm-level, diffusion of information technologies explains firms' organisational practices.

> Most of the managerial challenges at Dell Computer have to with what we call velocity – speeding the pace of every element of our business. Life cycles in our business are measured in months, not years, and if you don't move fast, you're out of the game.
> Kevin Rollins, Vice Chairman of Dell Computer Corporation (quoted from Magretta, 1998)

It is widely felt among practitioners that firm reactivity to change matters today more than ever (Stalk, 1988; Stalk and Webber, 1993; Magretta, 1998). Consequently, emphasis has been put on 'just in time' management methods, decentralisation 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'.

How can a firm improve its reactivity? It has long been known that time-to-market – the delay between product design and final delivery – depends heavily on organisational design. Well before economists, sociologists from the Contingency Theory School (Burns and Stalker, 1961; Woodward, 1965) have emphasised two ideal types of organisation. First, decentralised firms, where informal and horizontal communication predominates have a comparative advantage at coping with the introduction of product or process innovations. Those firms rely on their

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[1] Such a view is held by Piore and Sabel (1984). There is indeed some statistically grounded evidence that firm level uncertainty has risen over the past twenty years; for an illustration, see Comin and Philippon (2005).

workers' skills, and have often been compared to craftsmen workshops. On the other hand, large bureaucracies, where processes and information flows are routinised, where know-how is embodied in rules and procedures, experience gains in efficiency but also difficulties to adapt to changes brought by innovations.

Hence, the efficiency/reactivity tradeoff has long been an important aspect of organisational design. But in this case, why do business people feel that reactivity has recently become more crucial? Conventional wisdom emphasises the role played by the widespread diffusion of information technologies in the emergence of new organisational practices. This article focuses on this issue and highlights an original mechanism: new technologies boost the value of innovation and R&D investment among firms; this makes competition on the product market tougher and triggers reorganisations toward more reactive forms. In constrast to the existing literature which stresses firm-level complementarities between technology and organisation, we rather emphasise the role played by competitive pressures at the industry-level.

We start our theoretical analysis 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, being less reactive increases future profit flows, but exposes the firm to the risk of being overtaken by its competitors. This overtaking effect is the specificity of the strategic use of time-to-market in competition. When innovation becomes more frequent, the risk of being overtaken is so large that firms cannot afford not to be reactive. We then endogenise innovation effort by modelling the process of entry explicitly. The explicit modelling of time-to-market allows us to evaluate here the impact of the diffusion of information technologies, which are argued to reduce delays in information processing and transmission. This analysis shows that reactivity and new technologies are complements *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 in turn promotes more reactive forms of organisations. Hence, the IT/reactivity complementarity arises in equilibrium, through firms' strategic interactions on the product market.

Thus, reactivity and technology are complements; by putting reactivity issues to the fore, our analysis focuses on one dimension of organisational design that has so far been neglected by economists interested in these issues; see Bresnahan *et al.* (2002); Caroli and Van Reenen (2001). However, our main contribution is to provide an economic explanation of why such a complementarity happens: firms competing on the same market all have an incentive to become reactive when IT diffuses. Our explanation is thus that the complementarity occurs at the *industry level.* While the existing literature largely agrees that there is a complementarity between new technologies and new organisation, their main argument is that the decisions to adopt new technologies and to reorganise are complements *at the firm level*; see the theory developed by Milgrom and Roberts (1990) and the case studies described by Brynjolfsson and Hitt (2000). Thus, by looking at equilibrium interactions, our theory has predictions that differ from the dominant view of the relation between organisation and technology.

We thus end the article by proposing a test of these predictions based on the French dataset REPONSE. First, consistently with Milgrom and Roberts (1990), we find a positive correlation between the implementation of just in time organisation – a reduction in time-to-market – within the firm and firm level IT adoption. Secondly, at odds with Milgrom and Roberts, this correlation is weakened – even rendered insignificant in some specifications – once we control for industry level IT adoption. Our equilibrium mechanism thus explains at least part of the complementarity between IT and flexible organisation. These results are robust to the use of alternative, but indirect, measures of increased organisational reactivity. Finally, we propose evidence consistent with the fact the IT diffusion causes an increase in the pace of innovation, in line with the way our macroeconomic complementarity works.

The article is organised as follows. Section 1 is devoted to a presentation of the model and the equilibrium analysis. Section 2 focuses on the diffusion of information technologies within this framework. Section 3 puts the main predictions of our model to the test, and Section 4 concludes.

1. The Model

1.1. *The Framework*

The framework presented below is based on the model of Schumpeterian growth developed by Aghion and Howitt (1992) and Grossman and Helpman (1991).

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

$$U_T = \int_T^{\infty} \ln(C_t)\mathrm{e}^{-\rho(t-T)}\mathrm{d}t \tag{1}$$

where C_t is an index of consumption at date t, and ρ is the subjective rate of discount. 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: $\dot{E}_t/E_t = (r_t - \rho)$. We then normalise E_t to 1, which ensures that $\forall t,\ r_t = \rho$. The consumer purchases a continuum of goods indexed by $i \in [0; 1]$. These goods are subject to quality improvements through innovations. C_t as a function of the consumptions of the different goods and their respective qualities is given by:

$$\ln C_t = \int_0^1 \ln\left[\lambda^{s(i)} c_t(i)\right]\mathrm{d}i$$

where $\lambda > 1$, $s(i)$ denotes the number of innovations experienced by good i since the beginning of time, and $c_t(i)$ the quantity of i consumed at date t. Under this specification $x_t(i)$, the demand addressed to sector i, depends on its price $p_t(i)$ in a simple way:

$$x_t(i) = 1/p_t(i). \tag{2}$$

In each sector, research laboratories produce innovations according to a Poisson process of flow probability θ. In this activity, technology has constant returns: $\theta(i) = l(i)^{RD}/b$ where $l(i)^{RD}$ is the number of researchers searching for an innovation in sector *i*. Once found, patents are sold by laboratories to an infinity of potential final good producers; hence a successful R&D firm can capture the whole value of the patent exploitation. We further assume that laboratories cannot direct innovations toward a specific sector *i*.

In each sector *i*, risk neutral producers use labour according to a constant return technology $y = al$ where a is the endogenous level of productivity (see below). Different patent owners in sector i compete in price to sell their goods to the consumer. In equilibrium, as it is standard in this kind of literature, only a single supplier is actually producing: the one with the lowest quality price ratio. Quite simply, the unit cost function of a firm is given by $c(a, w) = w/a$.

Our model emphasises issues related to *time-to-market*, i.e. the delay between conception, production and actual delivery. The model thus assumes that, once the firm has bought a patent, it cannot produce and sell for a given time interval t. After this delay expires, production takes place according to the technology described above.

In this model, both time-to-market t and the level of productivity a are endogenous. The decision we focus on is the following: by choosing specific features of their organisation, firms may be more reactive and reduce time-to-market t, but the cost of such a decision comes through a lower operating productivity a. More specifically, just after the patent purchase, we allow firms to choose between a *mechanistic* organisation m, and an *organistic* one o such that:

$$\begin{cases} t_o < t_m : & \text{an organistic firm is more reactive.} \\ a_o < a_m : & \text{a mechanistic firm is more efficient at producing.} \end{cases} \tag{3}$$

We thus assume that there is a trade-off between producing more efficiently and increasing reactivity. The view that organisations differ in their degree of reactivity is not new to this article. In mainstream economics, it was first emphasised by Aoki (1986) in his study of the organisation of Japanese firms. Following Coase (1937), he argues that a centralised organisation accounts for the externalities between different production units within firm, because it allows firms to coordinate the optimal allocation of resources. Thus centralisation increases efficiency. On the other hand, as shown by Radner (1993) and Bolton and Dewatripont (1994), the very act of collecting and centralising information by bounded rational agents consumes time. Consequently, innovation implementation requires more delay in a centralised organisation than in a decentralised one, but it will be done more efficiently.

We implicitly assume this organisational choice to be *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, negotiated 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.

1.2. *Preliminary Steps*

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: thus, we take the rate of creative destruction θ as given. This allows us to highlight the 'overtaking effect', which is the possibility for an organistic firm to use its superior reactivity to produce before a mechanistic firm that is in the process of implementing production. When environment becomes turbulent, overtaking becomes so likely that firms prefer to be organistic, even though it lowers their productivity.

In what follows, we consider only one sector, and thus unambiguously omit the sector subscript. At date τ, a given firm buys the patent and must choose its organisation. In the industry, a firm – the incumbent – is currently selling an input of quality λ_0 previously discovered at date $\tau_0 < \tau$. Other firms have made discoveries before τ, but after τ_0, but are not producing yet. We index these non-producing incumbents by their rank of appearance *i*, starting with 1 for the oldest one. We denote by (τ_i, a_i) respectively 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): $\Omega_\tau = \{(\tau_0, a_0), (\tau_1, a_1),\ldots,(\tau_j, a_j),\ldots,(\tau_n, a_n)\}$ is thus the state variable of our dynamic system.

1.2.1. *Profit function*

Consider a Bertrand competition between a producing incumbent of quality $\hat{\lambda}$ and a better quality firm achieving $\hat{\lambda}\lambda^{n+1}$ (a newcomer which is $n + 1$ quality steps ahead). Because of the unit elasticity of demand (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 the producing incumbent out of the market. Profits are given by: $\pi = (p - c)x$ where c is the newcomer unit cost and x is output. From (2) we get $\pi = 1 - c/\hat{c}$. But unit costs are given by $c = w/\lambda^{n+1}a$ and $\hat{c} = w/\hat{a}$. Thus the firm's profit function is:

$$\pi_{\hat{a},a,n} = 1 - \frac{\hat{a}}{\lambda^{n+1}a} \tag{4}$$

where $\hat{a}$ is the producing incumbent's and, a, the newcomer's productivity.

Equation (4) highlights the two potential sources of profit of a firm. It depends on its organisation choice relative to the producer $(\hat{a}/a)$ and its quality advance (n).

1.2.2. *Overtaking*

A firm is said to be overtaken if, before beginning to produce, a more up-to-date newcomer begins to sell its product. An example of this is displayed in Figure 1. Assume for instance that firm *A* bought a new patent at date τ_a. It has then chosen to be mechanistic (low reactivity, high time-to-market). Assume also that the next innovation is found slightly after τ_a, at $\tau_b = \tau_a + \varepsilon$, where ε is small, and that the next patent buyer (firm *B*) decides to be organistic. Its quality price ratio will be larger than firm *A*'s if $\lambda/p_B > 1/p_A$. Now, recall that firm *B*'s unit cost is w/a_o, and

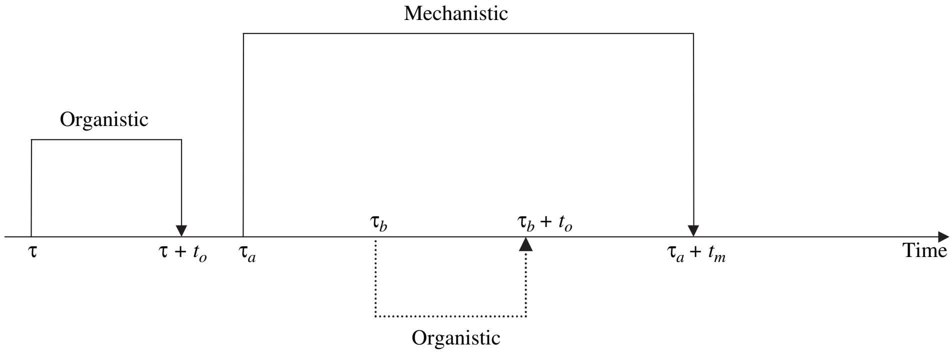

Fig. 1. *Example of Overtaking*

firm A's unit cost is w/a_m. Hence, if $a_m/a_o < \lambda$, the outsider B will be able to force A out of the market before A's production actually begins. Thus, A will never make any profit.

The possible existence of overtaking is very specific to the use of time-to-market as a strategic variable in competition; there lie the original predictions of our model. In order to highlight the importance of this mechanism, we make hereafter the two following assumptions

$$r(t_m - t_o) \ll 1 \tag{A1}$$

$$\frac{a_m}{a_o} \ll \lambda. \tag{A2}$$

Neither of these assumptions is actually necessary to obtain the equilibrium results stated below, but they allow us to single out the effect of overtaking expectations in equilibrium. Taken together, (A1) and (A2) state that a firm that has the opportunity to overtake will always do so and will therefore always choose to be organistic. (A1) guarantees that the opportunity cost of not producing incurred by slow reacting organisation is small. Hence, this opportunity cost will *not* be the reason for which firms prefer to be organistic. (A2) states that the productivity differential between an organistic and a mechanistic organisation is small when compared to the quality improvement brought by an innovation. If (A2) holds, a new entrant will make very large profits if it chooses to (and can) overtake a slower, mechanistic, competitor. Hence, (A2) guarantees that overtaking expectations are the most important force compelling firm to be organistic when they are in a position to overtake.

1.3. *Industry Level Equilibrium*

We now turn to the equilibrium analysis. As suggested in the two previous Sections, organisation choice is a strategic variable when firms compete with each other because they use productivity to boost their profits and time-to-market to overtake their competitors. More formally, a strategy $a(.)$ is a mapping between the set of *relevant*[2] histories $\{\Omega_\tau\}$ and the set of action $\{a_o, a_m\}$. Indeed firms' payoffs depend directly on relevant history Ω_τ for two reasons: first, because of Bertrand competition a firm's productivity choice depends on the other firms' productivities – this corresponds to the fact that $\hat{a}$ appears in (4). Secondly, a 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 (4).

We are in a position to derive existence conditions for two simple types of equilibria: A mechanistic equilibrium where firms' strategies consist of choosing to be mechanistic whatever history is $(a(\Omega_t) = a_m, \forall \Omega_t)$ and an organistic equilibrium where firms always play organistic $(a(\Omega_t) = a_o, \forall \Omega_t)$. To proceed, we use the 'one-shot deviation principle' which states that no player, whenever it is his turn to move, has an incentive to choose a different action. For example an organistic equilibrium is sustainable if in every subgame (i.e. for each Ω_τ) playing a_m is dominated by playing a_o.

In the Appendix we show that an organistic equilibrium always exists as long as θ, the rate of creative destruction, is large enough:

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

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

The intuition of Proposition 1 is the following. In an environment where all other firms choose to be organistic, a mechanistic firm takes advantage of its higher productivity to increase profit in price competition. On the other hand, its opportunity cost of delaying production is larger. But also, recall from (A1) and (A2) that firms that can overtake will always do so. Hence, being mechanistic exposes the firm to an overtaking threat by firms arriving on the market between τ and $\tau + t_m - t_o$. Both opportunity cost effects and overtaking threats lower the mechanistic organisation's expected value (see Figure 2). The point is, however, that an increase in θ does *not* affect the opportunity cost effect, but makes overtaking more and more likely. Hence, as the rate of creative destruction rises, firms lose more and more by being mechanistic.

Symmetrically a mechanistic equilibrium is sustainable when θ is small enough (see Appendix for a detailed proof):

[2] We restrict strategies to depend only on the set of 'relevant history' and not on the whole set of history. Consequently our analysis focus on Markov equilibria. Equilibrium defines the way a given firm chooses its 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 Van Damme (1990). The equilibrium definition goes as follows: the firm's sum of expected profits depends on relevant history Ω_t and the other players' 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 $\alpha = A(\Omega_t, a_{-1})$ (therefore a best strategy, or reaction function). The intersection of all reaction functions is a subgame perfect Nash equilibrium.

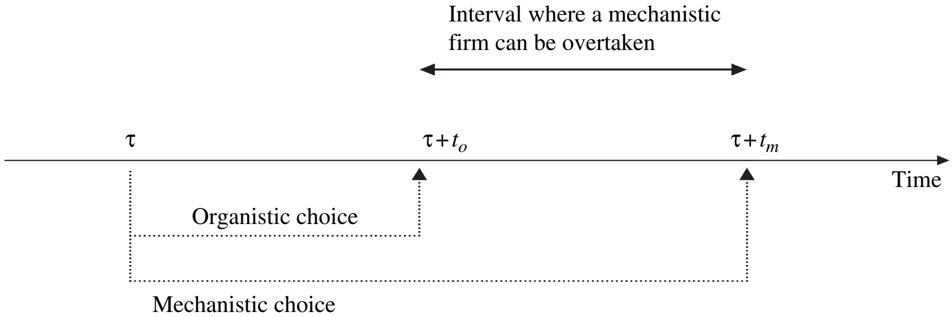

Fig. 2. *Organistic Equilibrium*

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

The overtaking effect is also at work here, but very differently. Let us now consider a firm arriving on the market at date τ in a mechanistic environment (see Figure 3). As before, mechanistic firms incur an opportunity cost of delaying production but there is no threat of overtaking – given that everyone is mechanistic. A single firm may, however, be willing to overtake its slow competitors, in particular when the previous incumbents are sufficiently 'bunched' around τ. In this case, the firm arriving at $\tau + \varepsilon$ may decide to overtake them and then make a very large, but temporary, profit. Indeed, assume n competitors innovated simultaneously at τ, the firm arriving at $\tau + \varepsilon$ who decides to be reactive will compete with an incumbent that has a productivity lower by a factor λ^{n+1}. This allows the overtaker to make very handsome profits for a short period of time, at the cost of being very inefficient afterwards. A decrease in θ makes the 'afterwards' period longer and dissuades firms from overtaking each other.

In both cases, the overtaking effect is the main force shaping the equilibrium. When innovation occurs frequently, overtaking by a competitor becomes very likely and firms prefer to go for the organistic organisation. When innovation occurs infrequently, firms find it very costly to overtake their competitors because short-run gains are small compared to long-run efficiency losses. This analysis yields insights similar to Thesmar and Thoenig (2000), albeit for very different reasons. Their model has no time-to-market but high productive efficiency requires the payment of an 'organisation' cost, sunk when the firm starts producing. Hence, high levels of creative destruction reduce the willingness of firms to be productive, as the horizon over which the sunk cost is amortised shrinks. The mechanism here is very different as it is the interaction between firms which drives the comparative static results. When choosing their level of reactivity, firms have to anticipate their likelihood of being overtaken. This in turn depends on their competitors' organisations, which are affected by the industry equilibrium. Hence, the strategic use of time in competition provides here a foundation for the reduced form sunk cost in Thesmar and Thoenig (2000). In addition to this, our explicit modelling of time here allows us to look at the impact of new technologies,

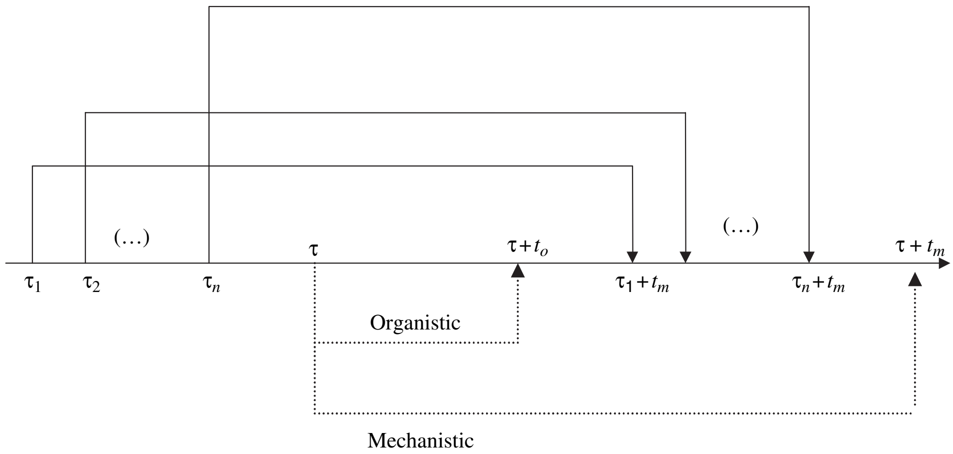

Fig. 3. *Mechanistic Equilibrium*

and to discuss the link between technology adoption and organisation design. We turn to this issue in Section 2.

1.4. *General Equilibrium: Properties*

In this Section, we endogenise the rate of creative destruction θ: this helps us to analyse the feedback effect of time based competition on the aggregate rate of growth.

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)–(4):

$$V_{\{o,m\}}(\theta) = \mathrm{e}^{-rt_{\{o,m\}}} \frac{1 - 1/\lambda}{r + \theta} \tag{5}$$

$$\text{where } t_{\{o,m\}} = t_m \quad \text{if } \theta < \theta^* \quad \text{and} \quad t_{\{o,m\}} = t_o \quad \text{if } \theta > \theta^* \tag{6}$$

$$\text{with } \theta^* \equiv \frac{(a_m/a_o) - 1}{\lambda(t_m - t_o)} - r. \tag{7}$$

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, as in the profit equation (4); 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:

$$bw = V_{\{o,m\}}(\theta). \tag{8}$$

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 aggregate 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:

$$L = b\theta + 1/\lambda w. \tag{9}$$

Using (8)–(9), general equilibrium is summarised by the single equation:

$$L = b\theta + \frac{b(r+\theta)}{\lambda - 1} e^{rt_{\{o,m\}}}. \tag{10}$$

Labour demand (the RHS of this equation) is not monotonic, 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 4, and more formally in the proposition below.[3]

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

(*i*) *if* $L \leq \underline{L}$ *then Industry is mechanistic in all sectors*
(*ii*) *if* $L \geq \bar{L}$ *then Industry is organistic.*
(*iii*) *if* $\underline{L} \leq L \leq \bar{L}$ *then Industry can be either mechanistic or organistic.*

The above proposition states that, for intermediate sizes of the 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 by $(V/b)l^{RD}$), which in turn raises its output, the growth rate θ. But from the preceding Section, we know that a larger rate of creative-destruction may render active the threat of being overtaken, and thus increases the comparative advantage of organistic organisations.[4]

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. It can also be shown that, for a given $L \in [\underline{L}; \bar{L}]$, the 'organistic'

[3] If we look at (10), we easily get that an organistic equilibrium is sustainable iff $\theta \geq \theta^*$. This inequality can be rewritten as: $L > \underline{L} \equiv b\theta^* + [b(r+\theta^*)/(\lambda - 1)]e^{rt_m}$. A mechanistic equilibrium is sustainable iff $\theta \leq \theta^*$, or $L < \bar{L} \equiv b\theta^* + [b(r+\theta^*)/(\lambda-1)]e^{rt_m}$. We then get straightforwardly that $\underline{L} < \bar{L}$.

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

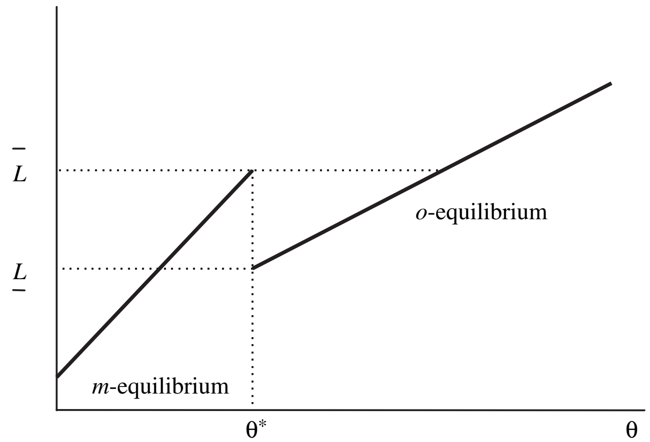

Fig. 4. *Labour Demand*

equilibrium exhibits a higher level of creation destruction θ, a higher level of firm valuation and lower level of production than the 'mechanistic equilibrium'.

2. Information Technologies and Organisation Change: a Macro-founded Complementarity

We now are in a position to investigate the specific impact of information technology diffusion on the equilibrium. Below, we will argue that *IT diffusion allows firms to reduce time-to-market*, i.e. the delay between conception, production and delivery to the final consumer. This seems natural as information technology enhances the abilities of the firm to both process and communicate information. Better information processing and communication make firms naturally more reactive. To cite a few examples at all points of the value chain, IT allows the firm to

(1) follow demand changes more closely (through built-to-order production systems);
(2) speed the process of innovation itself – using computers to make simulations instead of costly experiments;
(3) reprogram production units costlessly in order to adapt them to changing product specification (through the use of computer controlled equipment); and
(4) coordinate better with distribution networks and suppliers in order to avoid both bottlenecks in the production process and high levels of inventories (what experts call 'supply chain management').

Before we proceed any further in our comparative static exercise, we need to ask whether there exists an asymmetry between the effect of IT on reactivity of organistic and mechanistic organisations. Does IT enhance the reactivity of both organisations in the same proportions ? Does it give a comparative advantage to any of them? There is a large literature at the frontier of management science and economics about the complementarity between the diffusion of information technologies and the adoption of new forms of organisations; see for instance the review by Brynjolfsson and Hitt (2000). This literature develops the following vision: to take full advantage of enhanced information processing and communication, firms must adopt much more decentralised structures, empower the lowest levels of the hierarchy, suppress intermediate hierarchical layers, stimulate autonomous decision making in groups and foster coordination across divisions.[5]

This literature thus emphasises how reactive (organistic) organisations are a natural *complement* to new technologies while tayloristic (mechanistic) organisations were a good complement to old general purpose technologies. Milgrom and Roberts (1990) have put forward a formalised version of this view. In our framework, this view translates into:

$$\begin{cases} t_m & \stackrel{IT}{\rightarrow} t_m - \delta \\ t_o & \stackrel{IT}{\rightarrow} t_o - \delta - \Delta, \end{cases} \tag{11}$$

which means that IT reduces time-to-market for both types of organisations but intrinsically favours the organistic type of organisation. Then, quite obviously, our model would predict IT diffusion should be accompanied with a diffusion of organistic organisation.

However, as natural as it seems, this view of firm level complementarity faces at least two caveats. First, it puts too much emphasis on technology as a determinant of organisation choice. It omits the fact the organistic, more reactive, organisations – with more delegation, flatter hierarchies, more informal internal communication, loose procedures and multitask workers – existed *before* information technologies diffused in the economy. This is the main discovery behind the Contingency Theory literature (Burns and Stalker, 1961), exemplified in Woodward's (1965) study on the prevalence of organistic organisations in the 1960s British electronics industry. In Japan, Toyota also introduced its 'flexible' production system in the 1960s: in order to improve product quality and reduce inventories, workers at the shop floor level were granted more autonomy and horizontal communication took a more important part in overall coordination. As put forward by Contingency theorists forty years ago, product market considerations like competition and need for reactivity also matter for the design of the optimal organisation.

The second concern is that economic theory has trouble explaining why information and communication technologies make delegated, rather than centralised, organisations optimal (Bolton and Dewatripont, 1994). An important obstacle

[5] Put in general words, the idea that optimal production organisation depends on production technology is not new: modern bureaucracy could never have emerged without the sharp decrease in production costs of paper and ink in the early nineteenth century. It took nearly half a century for electricity to generate strong productivity gains because it took that long to American entrepreneurs to figure out the optimal organisation of a firm using electricity instead of steam engines. As it turned out, electricity elicited Taylorism because its flexibility allowed to push the gains to specialisation further than steam (David, 1990).

faced by organisation theorists is that, given that IT decreases the costs of communicating and increase information processing ability, IT should make centralised organisations much more efficient. Hence, it is not completely obvious why IT unambiguously promotes decentralisation. For a recent attempt at rationalising the complementarity between decentralisation and IT, see, however, Dessein and Santos (2003).

For these two reasons, we choose to abstract, in our analysis of IT diffusion, from a possible built-in asymmetry between organistic and mechanistic organisations. In assumption (11), we therefore posit that $\Delta = 0$; IT reduces time-to-market in a similar way for both mechanistic and organistic. Even if it is not necessarily realistic, this assumption allows us to focus on the specific lessons our model can bring. Indeed, the specificity of our model is that it allows us to address the issue of organisation choice *in equilibrium*: by reducing time-to-market, we do not assume any advantage for any type of organisation, and ask whether resulting equilibrium changes affect organisation choices.

As it turns out, IT diffusion favours the adoption of organistic organisations, but through equilibrium effects. First, notice that reduction of time-to-market by δ does not change the threshold θ^* on product market competition, above which firms adopt an organistic organisation; see (1). Since the relative efficiency of both organisations remains the same, the trade-off underlying the organisation choice is not affected by IT diffusion. IT does, however, induce an increase in the rate of innovation θ for a given supply labour L, because it makes R&D more productive. Indeed the equilibrium condition (10) becomes:

$$L = b\theta + \frac{b(r+\theta)}{\lambda - 1} \mathrm{e}^{r\left(t_{\{o,m\}} - \delta\right)}.$$

A reduction in time-to-market by δ multiplies the value of patents by $e^{r\delta} > 1$, it therefore shifts the labour demand curve pictured in Figure 4 downwards. This triggers entry into the R&D industry which increase the rate of innovation θ. If θ increases above the unchanged threshold θ^*, firms fear of being overtaken and choose more reactive organisations. All firms become organistic.

Hence, our framework proposes an explanation why IT diffusion is accompanied with the mass adoption of more reactive – though less efficient – organisations. The complementarity arises in equilibrium, through competition on the product market to deliver goods as soon as possible. The existence of such a macro-complementarity comes from the 'overtaking expectation' effect we discussed above and is therefore specific to the use of time-to-market as a strategic variable on the product market.

3. The Nature of the Technology – Organisation Complementarity: Empirical Evidence

3.1. *Three Hypotheses*

Our model thus focuses on one aspect of organisational design: the reactivity/efficiency trade-off. When firms are allowed to make this choice, our theoretical analysis shows that information technologies promote the choice of more reactive/less efficient organisations. This type of complementarity is already documented in the literature (Bresnahan *et al.*, 2002; Milgrom and Roberts, 1990). The focus of most studies, however, has not been the reactivity/efficiency trade-off that we look at. Bresnahan *et al.* (2002) tend to focus on delegation aspects, while Caroli and Van Reenen (2001) look at the causes and consequences of delayering. Hence, we derive the first original prediction of our model:

HYPOTHESIS 1 *(Reactivity and IT use are complements): Firms making more use of information technologies should, other things equal, have more reactive organisations.*

The second prediction of our model has to do with the mechanism of this organisation/technology complementarity and is therefore much more specific to our analysis. Given that IT *a priori* increases the reactivity of both organistic and mechanistic organisations, there is no obvious economic reason for which it should favour one over the other *at the firm level*. Starting from this 'neutrality' assumption, our theoretical analysis highlights that the complementarity still exists but arises in equilibrium: IT investments at the industry level trigger firms' reorganisations because they increase the pace of product market change and therefore the threat of being overtaken. Hence, gains of being reactive become larger and firms accept to lose some productive efficiency. This suggests a second hypothesis:

HYPOTHESIS 2 *(At least some complementarity is macro): Firms adopt more reactive organisations not only when they themselves invest in IT but also when their competitors do so.*

In the model, the macroeconomic complementarity works through the intensification of competition on the product market. IT improves the value of all adopting firms, which triggers more R&D and reorganisation. A simple by-product of this mechanism is that industries where IT is the most diffused should be industries where innovation effort (R&D spending) is largest. We state here the last prediction that IT adoption causes an increase in R&D activity:

HYPOTHESIS 3 *(IT spurs growth): Industries where IT diffusion is high should subsequently witness an increase in R&D spending.*

In the following we provide tests for these three hypotheses. A key issue here is measuring such things as R&D, IT investment, and more importantly – and difficult – organisation reactivity. We will be able to do this by using both firm level data from the French REPONSE survey on organisation, as well as industry data on R&D spending. Before proceeding to the tests themselves, let us first present the data and the measures they allow us to use.

3.2. *Brief Data Description*

To test our three hypotheses, we need three types of variables: information on R&D effort, IT use and organisational reactivity. R&D information will be used to test hypothesis 3 only. We do not have firm level data on R&D spending, so we will have to content ourselves with industry data. We obtained total R&D investment aggregated at the industry level from the French Ministry of Industry. Series are available over the 1992–2000 period for 17 manufacturing industries, construction, telecommunication and business services.[6]

But our main predictions bear on firm organisation and IT adoption. To obtain information on these two items, we use firm level data from the French REPONSE survey (*Relations professionnelles et négociations d'entreprises*).[7] It is the second in a series of mandatory surveys that began in 1992 (Caroli and Van Reenen, 2001) and is jointly conducted by the French Statistical Office (INSEE) and the Ministry of Labour. Its primary aim is to provide statistically reliable and nationally representative data on the current state of workplace relations and employment practices in France; it also gives detailed information on technology in use and workplace transformations. An interdisciplinary committee including economists, management scientists and sociologists designs the questionnaire. Questions, especially on work organisation, are first tested with a small sample of managers or workers to verify if their meanings are correctly understood.

The REPONSE 98 cross-section survey includes three sub-surveys that provide firm level data collected from

(1) interviews held with managers,
(2) interviews held with worker representatives and
(3) questionnaires employees were invited to fill in on the workplace.

This survey has been conducted during the first months of 1999 and questions deal with the work organisation in 1998. Some 2,800 firms are surveyed; the sample is representative of French private establishments employing more than 20 employees in manufacturing, construction and services.

We only use the information collected from managers because the information on technology and organisation is more complete in that part of the survey and also because managers are expected to hold a more accurate view of the global workplace organisation than workers or their representatives. Managers participating in the survey were usually the most senior managers in the workplace with responsibility for employment relations. They were asked mainly factual questions covering a wide range of issues that deal with the employment relationship. Some examples include: technology use, business strategy, recruitment and training, reliance on external consultants, worker representation, flexibility and attitudes to work.

Some variables allow us to measure the use of information technologies at the firm level. As most French establishments actually use computers, we focus on a more discriminating variable: the use of computer networks (internet, intranet). Indeed in France the internet really began to diffuse in business activities in 1997. Therefore, establishments connected in 1998 were the most IT advanced. In addition to providing enough variability in the model, the use of this 'network'

[6] This dataset was kindly provided by Stéphane Lhuillery.
[7] These data are exploited under a convention with the French Ministry of Labour.

variable fits our theoretical description of IT: a technology that enhances the ability to observe demand changes and to follow orders and shipments in real time. This improvement in communication both within the firm (intranet) and between the firm and the outside world (customers, suppliers through the internet) really corresponds to the comparative static exercise we performed by reducing time-to-market. Therefore, we define an establishment as IT intensive if, in 1998, it has an intranet and it is connected to the internet; the binary variable *NET* takes the values 1 in this case and 0 otherwise. Following this definition, about half of all establishments in our sample are IT intensive.

Not surprisingly, the survey does not directly measure time-to-market, as defined by the delay between product conception and final delivery. However, case studies as those gathered by Cohen *et al.* (2004), show that the reduction of time-to-market requires the implementation of work practices grouped under the 'Just-In-Time' (JIT) label. While JIT initially referred to the low inventory policy implemented by Toyota in the 1960s, it now consists of an organisation that *guarantees* an 'immediate' delivery (within some days), in particular of innovative or customised goods and services. To be more precise, two types of JIT can be distinguished: 'JIT with customers', where the firm commits to immediate delivery to its customers and 'JIT with suppliers', meaning that the firm requires immediate delivery from its suppliers. A complete JIT organisation combines these two aspects. Well-known examples of such organisations are Zara and H&M, two leading European firms in the clothing industry (both in manufacturing and retailing). The results achieved in terms of time-to-market are impressive: it takes only two weeks for the Spanish Zara and three weeks for Scandinavian H&M between the conception of a new piece of garment and its availability in one of the stores of the chain (Cohen *et al.*, 2004).

The REPONSE survey 1998 has a question asking if the surveyed establishment has a JIT organisation.[8] The answers to this question is informative because JIT is a terminology well known to French managers ('juste à temps' in French). The JIT question is broken down into two parts: 'JIT with customers' and/or 'JIT with suppliers'. To proxy for time-to-market, we thus use the *OJIT* categorical variable. $OJIT = 2$ if the establishment has a 'Just-In-Time' organisation with both its customers and with its suppliers (26% of all firms). $OJIT = 1$ if the establishment just has a 'Just-In-Time' organisation with its customers (14% of all firms). Otherwise, we set *OJIT* to 0 (60%). Because short time to market in the model requires JIT with customers, we set $OJIT = 0$ for establishments using JIT only with suppliers. This somewhat arbitrary assumption, however has no effect on our estimates since these cases only represent 5% of the sample.

Numerous other questions or administrative information will be used as controls. We keep variables that can affect both organisational and technological choices such as status (mono-establishments, affiliated to a corporate group), union representation, composition of the workforce, employment, evolution of

[8] More precisely, the question is 'For the following methods and technologies, can you indicate which ones are used in your plant ?'. The (non-exclusive) answers can be (1) numerically controlled machine tool, (2) computer aided systems, (3) just in time with suppliers, (4) just in time with customers, (5) delayering and (6) total quality management.

the activity (decreasing, stable or increasing), boundary of the market (local, regional, national, European, international), share of the main client, industry, etc. The complete set of controls is detailed in Appendix B. We will also look at other aspects of organisation that have been considered in the existing literature and which correspond to information given in the REPONSE survey (such as delayering and human resource management practices like as job rotation and team empowerment).

3.3. *Organisation/Technology Complementarity*

This Section tests Hypotheses 1 and 2. We do not claim to test the *causalities* implied by these hypotheses here but simply to test the cross sectional relations predicted by the model. As it turns out, given the nature of the problem we address and the data we use, our cross sectional approach bears some resemblance to a first difference approach in panel data. Given the speed of diffusion of computer networks and organisational innovations, it seems safe to assume that very few firms in our sample had either a JIT organisation (highly probable) or networking technologies in the early 1990s (certain for the internet). In this sense then, a cross-sectional analysis of our 1998 REPONSE survey is analogous to correlating evolutions between 1990 and 1998. It is not clear, however, that even a cleaner panel approach would help us to provide endogeneity-free econometric estimates, since firms experiencing reorganisations are *not* a random sample. In this context, an instrument, rather than a real panel, would be the solution.

Let us first turn to the test of Hypothesis 1, namely that IT adoption and time-to-market shortening are complement. To test this, we run the following regression:

$$OJIT_i = c + \alpha NET_i + \beta \text{controls}_i + \varepsilon_i \tag{12}$$

where obviously, hypothesis 1 is that JIT organisation and the use of Net technology are positively correlated (i.e. $\alpha > 0$).

Given that *OJIT* is categorical, we model (12) as an ordered probit and report estimation results in Table 1, columns 1 to 3. We propose three different specifications of (5): without control, using various firm level variables that could cause both technology adoption and organisation reactivity, and including both these variables and industry dummies. As expected, JIT organisation is strongly and robustly correlated with the use of computer networking technologies. The unconditional estimate is high but partly captures the effects of other firm level characteristics. When we include them, it is divided by two but remains significant at 1%. Last, the inclusion of industry dummies partly reduces significance – to 5% – but the coefficient size is not affected, which hints at the fact that we might be starting to face identification problems. These findings are consistent with the existing empirical studies on the complementarity between organisation and technology (Bresnahan *et al.*, 2002; Caroli and Van Reenen, 2001). They also are consistent with the theoretical view held by Milgrom and Roberts (1990) that information technology and new organisations are complementary decisions at the firm level.

As we mentioned above, however, the specificity of our theory is that we have economic reasons for which these complementarities arise. This is Hypothesis 2: firms do not reduce time-to-market because they themselves adopt information technologies *but because their competitors do*. Equation (12) is not discriminating enough: a significantly positive value of α is compatible both with firm level complementarity and industry level complementarity. A more discriminating test would be to look at the correlation of JIT with both firm level technology adoption and industry level technology diffusion. If our theory is correct, industry level technology should matter, even when one controls for firm level technology use. This intuition suggests the estimation of the following model:

$$OJIT_i = c + \alpha'(NET_i - NET_{industry}) + \gamma NET_{industry} + \beta' \text{controls}_i \qquad (13)$$

where $NET_{industry}$ is the simple average value of *NET* over all observed establishments in the industry the establishment belongs to.[9] The coefficient α' measure the strength of the 'Milgrom-Roberts' firm level complementarity, while γ measures the industry level complementarity that is specific to our theory. Hence, this empirical test allows to evaluate the respective strength of both theories: α' is the strength of firm level complementarity and γ is the strength of our industry complementarity.

Estimates of (13) using various controls and various sub-samples are given in Table 1, columns 4 to 8. Industry level technology diffusion is computed using the 2 digit French industry classification NAF85. Firm level technology use still predicts a shortening of time-to-market ($\alpha' > 0$). The coefficient is statistically significant at 5% and is similar in size to that obtained from previous estimates (columns 2–3). The news is that the industry effect is much larger and statistically different from zero at the 1% level. Initially larger than 2, its size drops to 1.2 after including the firm level controls. We then perform various robustness checks. We first restrict estimation to industries including at least 11 establishments (column 6) because a small number of observations in a given industry may make the individual and industry effects hard to distinguish. Estimates for both α' and γ are unaffected. Second, since firms' reactions are not independent within industries, it is worthwhile computing standard errors that are robust to within industry correlation of error terms (column 7); in this case, the firm level effect remains significant at the 5% level, but we clearly reach the limits of what the data allow us to identify. Even under these circumstances, however, the coefficient on industry level technology diffusion remains the same size and significantly at the 5% level. In the last regression, we focus on manufacturing and construction only: it appears that there the firm level complementarity is smaller (coefficient smaller and insignificant) and that the industry level complementarity is larger (coefficient 1.8 and significant at 1%). All in all, these results suggest that industry complementarity is more robust than firm level complementarity.

We cannot completely rule out the fact that our estimates reveal the high level of measurement error of NET_i when compared to its 'smoothed' industry level

[9] It therefore includes the establishment of interest. To test whether this method does not induce spurious correlation between $OJIT_i$ and $NET_{industry}$, in some specifications we restrict the sample to establishments belonging to industries with more than 11 firms.

Table 1

Use of IT and Just-In-Time

	Depend Variable: OJIT (Ordered logit)							
	(1)	(2)	(3)	(4)	(5)	(6) >10 obs by ind.	(7) >10 obs clusters	(8) >10 obs cl,manuf
Test variables								
NET: Intranet + Internet	0.48**	0.27**	0.23*	–	–	–	–	–
	(0.08)	(0.10)	(0.10)					
$(NET - NET_{industry})$	–	–	–	0.21*	0.22*	0.17*	0.17	0.13
				(0.08)	(0.10)	(0.08)	(0.11)	(0.12)
$NET_{industry}$	–	–	–	2.08**	1.26**	1.08**	1.08*	1.87**
(by detailed industrial classification)				(0.20)	(0.31)	(0.33)	(0.47)	(0.69)
Controls								
Multi-establishment	–	yes	yes	–	yes	yes	yes	yes
Listed firm	–	yes	yes	–	yes	yes	yes	yes
Workforce Composition	–	yes	yes	–	yes	yes	yes	yes
Size	–	yes	yes	–	yes	yes	yes	yes
Unionisation	–	yes	yes	–	yes	yes	yes	yes
Dynamism	–	yes	yes	–	yes	yes	yes	yes
Market Frontiers	–	yes	yes	–	yes	yes	yes	yes
Main Client Sales Share	–	yes	yes	–	yes	yes	yes	yes
16 Industry Dummies	–	–	yes	–	–	–	–	–
Observations	2,753	2,195	2,195	2,753	2,195	2,111	2,111	975
Log likelihood	−2,563	−1,883	−1,835	−2,525	−1,878	−1,801	−1,801	−928

Source. 1998 REPONSE survey on French establishments from the private sector with 20 or more workers.

Note. in all regressions, the dependent variable is *OJIT*, a categorical variable constructed using the REPONSE survey (for more extensive details, see main text). $OJIT = 2$ if the firm is able to deliver its products 'just in time' to its customers and requires 'just in time' delivery from its suppliers. $OJIT = 1$ if the firm only delivers 'just in time' to its customers. $OJIT = 0$ when the firm does not make such a commitment to its customers. NET_i is a variable equal to one if the firms claims to use either internet or an intranet, and zero else. $NET_{industry}$ is the industry mean of NET_i. Column 1 only uses the firm level IT diffusion variable as control. Column 2 includes various controls and column 3 further includes industry controls. Columns 4 and 5 replicate columns 1 and 2 but use, instead of NET_i, the industry average IT diffusion $NET_{industry}$ and the difference between firm and industry level diffusions $NET_i - NET_{industry}$. Column 6 focuses on industries that have at least 10 plants surveyed in REPONSE. Column 7 further allows for flexible correlation of residuals within each industry, à la White. Column 8 replicates column 7 on manufacturing. As OJIT can have only three values, all regressions use an ordered logit specification. Standard errors are between parenthesis. ** denotes 1% level significance, while * denotes 5% level significance.

counterpart. In this case, the estimate for NET_i should be mechanically smaller and less significant. A first defence is the great care with which the REPONSE survey was conducted: the questionnaire was initially tested on a subsample to see if responders understood the questions correctly; in addition, after the survey, a subsample of firms was selected to check on the field the quality of the answers. What is also partially reassuring for our thesis is that the coefficient associated with $NET_{industry}$ is at least 5 times larger than the coefficient of $NET_i - NET_{industry}$, while the ratio of the standard deviations of $NET_i - NET_{industry}$ (e.g. 0.46 for the full sample) and of $NET_{industry}(0.19)$ is below 2.5. This last discussion suggests that, in addition to being more significant, the industry effect is much larger in terms of magnitude than the firm level effect.

Other workplace practices have been argued to reduce time-to-market. The reduction of the number of layers in the hierarchy (delayering) increases the speed of decision making because it saves time otherwise spent on communicating with and convincing the hierarchy. It also leaves more autonomy at the lowest layers of the hierarchy, i.e. to people closer to operation. Another way to give autonomy, while keeping some control over work quality, is to endow, not the workers themselves, but *groups* of workers, with more decision making power. This makes the organisation more reactive but still prevents uncoordinated and/or aberrant decisions to be made. Organised job rotation is another practice that allows improving coordination at the level of the workplace, dispensing with part of the hierarchy and therefore speeding up decision making. Ordered job rotation allows workers to know each other's work and internalise the impact of their own decisions on the rest of the production process.

The REPONSE survey allows us to measure whether firms indeed have adopted any of these three practices: delayering, group autonomy and ordered job rotation. The variable *DELAYERING* equals one when the manager reports the suppression of a layer of hierarchy in the firm's recent past. The variable *AUTO* is 2 if more than 20% of all workers are involved in autonomous work groups, 1 if some workers (but less than 20%) belong to such groups and 0 else. *JOBROT* is set equal to 2 when more than 35% of all workers are involved in job rotation, 1 if some workers are involved in job rotation (but less than 35%) and zero else.

We thus assume that these practices shorten time-to-market for the firm which adopts them. Table 2 reports tests of hypothesis 2 for these three practices. All regressions control for firm level characteristics. Columns 1, 3 and 5 look at the correlation between each of the three organisations and firm level IT use. Except in the case of ordered job rotation, correlations are strongly positive and significant; hence, new organisational practices are complemented by *NET* use, apparently at the firm level. When we include technology diffusion at the industry level, empirical results fit our theoretical predictions. Controlling for firm level adoption of new technologies, the implementation of these practices is again very strongly correlated with industry level technology diffusion. Except in the case of job rotation, firm level correlation remains strong and significant, consistently with hypotheses (1) and (2) being true.

Table 2

Use of IT and Other Workplace Practices

	Ordered Logit (More than 10 observations by industry)					
	(1)	(2)	(3)	(4)	(5)	(6)
	De-Layering		Autonomous Team		Job Rotation	
NET: Intranet + Internet	0.58**	–	0.78*	–	0.10	–
	(0.11)	–	(0.10)		(0.09)	
$(NET - NET_{industry})$	–	0.51**	–	0.74**	–	0.03*
		(0.11)		(0.09)	–	(0.10)
$NET_{industry}$	–	0.92**	–	1.69**	–	1.52**
(by detailed industrial classification)		(0.39)		(0.57)	–	(0.55)
Controls						
Multi-establishment	yes	yes	yes	yes	yes	yes
Listed firm	yes	yes	yes	yes	yes	yes
Workforce composition	yes	yes	yes	yes	yes	yes
Size	yes	yes	yes	yes	yes	yes
Unionisation	yes	yes	yes	yes	yes	yes
Dynamism	yes	yes	yes	yes	yes	yes
Market frontiers	yes	yes	yes	yes	yes	yes
Main client sales share	yes	yes	yes	yes	yes	yes
Observations	2,131	2,131	2,118	2,118	2,148	2,148
Log likelihood	−1,250	−1,242	−1,865	−1,860	−2,200	−2,188

Source. 1998 REPONSE survey on French establishments from the private sector with 20 or more workers.

Note. in all regressions, NET_i is a variable equal to one if the firm claims to use either internet or an intranet. $NET_{industry}$ is the industry mean of NET_i . The dependent variable in columns 1 and 2 equals to 1 if the firm claims to have recently 'shortened' its hierarchy, and zero otherwise. The dependent variable in columns 3 and 4 is equal to 2 if the firm claims to have more than 20% of its workforce clustered in 'autonomous work groups', to 1 if some workers but not all, belong to such groups, and zero elsewhere. The dependent variable in columns 5 and 6 is equal to 2 when more than 35% of all workers are involved in job rotation, 1 if some workers are involved in job rotation (but less than 35%) and zero elsewhere. Columns 1, 3 and 5 include firm level controls and NET_i. Columns 2, 4 and 6 include instead the industry average $NET_{industry}$ and the difference between firm level and industry level technology diffusions: $NET_i - NET_{industry}$. Columns 1 and 2 present the results of a logit estimation; Columns 3, 4, 5 and 6 present the results of an ordered logit model. Standard errors are in parenthesis. ** denotes 1% level significance, while * denotes 5% level significance.

3.4. *Does Time Competition Spur Growth?*

In our framework, IT diffusion implies a reduction in time-to-market because IT diffusion enhances the value of innovation, which in turn accelerates the process of creative destruction and compels firms to shorten time-to-market. This corresponds to Hypothesis 2, which we successfully test in the previous Section. A by-product of this mechanism is that IT diffusion should raise R&D spending. This is Hypothesis 3, for which we now gather some support. We could content ourselves with looking at the cross-section correlation between IT diffusion and R&D spending. But since the mechanism implied by Hypothesis 3 is causal, we test more stringently whether IT diffusion is *followed*, not led, by an increase in R&D at the firm level.

The REPONSE survey does not have firm level data on R&D spending, but we obtained industry level data over the 1992–2000 period (REPERES database, French Ministry of Research). Obviously, comparisons can only be illustrative

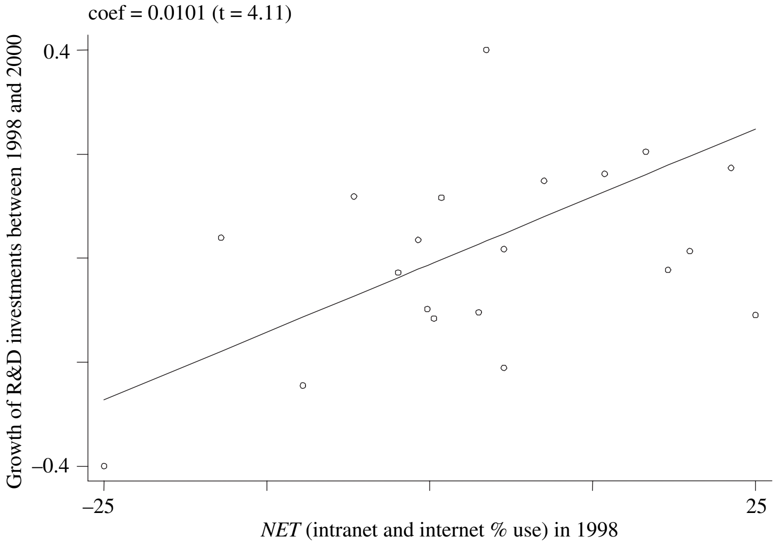

Fig. 5. *1998 Internet Use and Ex Post R&D Growth for Some French Industries.*

because of the volatility of annual R&D investments and the small number of observations. Figure 5 reports the estimated proportion of establishments using *NET* technologies in 1998 (from the REPONSE survey) plotted against the log increase of industry investments in R&D. A linear regression confirms the clear positive relation between *NET* in 1998 and the *ex post* increase in R&D efforts between 1998 and 2000. It could, however, be the case that there is more IT diffusion into industry doing more R&D because, say, firms doing R&D use more IT for their research. While our industry level data is to crude to completely reject that hypothesis, we examine in Figure 6 the correlation between 1998 IT diffusion and *ex ante* R&D spending (we compute industry R&D spending growth between 1995 and 1998). As it turns out, there is no apparent correlation between the use of *NET* in 1998 and the increase of R&D effort between 1995 and 1998 (see Figure 6). This lends further credence to our causal hypothesis.

4. Conclusion

Time based competition is a term coined from the business literature for describing the set of organisational strategies aimed at reducing the time-to-market of new products. This article is a first attempt at introducing time based competition, at assessing its specificity, its potential determinants and impacts on growth. When firms strategically use time-to-market in competition, 'overtaking' considerations dominate. When the pace of product market change accelerate, firms prefer reactivity to productive efficiency and switch to organistic organisations.

The model provides a simple and original explanation as to why information and communication technologies may have triggered the diffusion of more reactive organisations. In contrast with the existing literature, which has focused

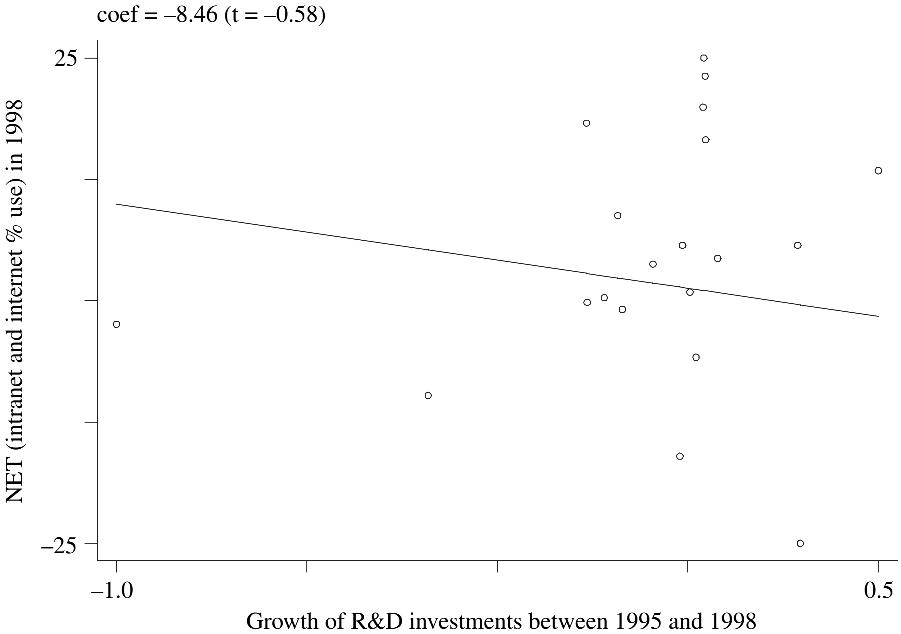

Fig. 6. *1998 Internet Use and Ex Ante R&D Growth for Some French industries*

on firm level complementarity between new organisational designs and new technologies, our theory emphasises the role of macroeconomic complementarity. IT investment increases the value of innovation, which boosts R&D investment among firms; as competitors enter more often, time competition is tougher, which triggers reorganisation.

This 'macroeconomic' channel of complementarity is then tested on French data. In particular, firms reduce time-to-market more often when their competitors have adopted new technologies, while the firm level complementarity appears to play a smaller role. This is confirmed using several organisational variables. This consequently supports the view that waves of reorganisations observed several times in history, and recently with the emergence of reactive organisation, may be only related to the diffusion of new technologies *through competitive pressure.*

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Appendix A

Proof of Proposition 1: Let us assume that the equilibrium strategy is given by $a^*(\Omega_\tau) = a_o$. 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, $\tilde{\Omega}$, 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 (organistic) are the highest (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 (mechanistic), we refer to the history as being $\tilde{\Omega}_o$ ($\tilde{\Omega}_m$).

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 2). Profits are given by (1): π_{oo} (π_{om}) is the profit if the firm chooses to be organistic (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 up-to-date innovator, the values of an organistic and a mechanistic firm are given by $V_{oo} = \underset{\eta}{\mathrm{E}}\left(\int_{t_o}^{\eta} e^{-r.s}\pi_{oo}\mathrm{d}s\right)$ and $V_{om} = \underset{\eta}{\mathrm{E}}\left(1_{\{\eta \geq t_m\}}\int_{t_m}^{\eta} e^{-r.s}\pi_{om}\mathrm{d}s\right)$. 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 exogenous Poisson process, straightforward calculations yield:

$$V_{oo} = e^{-t_o r}\pi_{oo}/(r + \theta) \tag{14}$$

$$V_{om} = \Pr(\eta \geq t_m)\mathrm{E}\left(\int_{t_o}^{\eta} e^{-r.s}\pi_{om}\mathrm{d}s\right) \tag{15}$$

$$= e^{-(t_m - t_o)\theta}e^{-t_m r}\pi_{om}/(r + \theta). \tag{16}$$

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

$$e^{(t_m - t_o)(r+\theta)} > (\lambda - a_o/a_m)/(\lambda - 1). \tag{17}$$

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:

$$e^{(t_m - t_o)(r+\theta)} > (\lambda - 1)/(\lambda - a_m/a_o). \tag{18}$$

A straightforward computation shows that (17) is always true when (18) is true. Hence, a firm always follows the equilibrium strategy $a^*(.)$ (i.e. playing a_o in every history Ω_τ) if and only if (18) is satisfied, which means that:

$$\theta \geq \frac{\ln[(\lambda - 1)/(\lambda - a_m/a_o)]}{t_m - t_o} - r. \tag{19}$$

Provided assumption (A1) holds, the condition (19) boils down to

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

Proof of Proposition 2 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 $a^*(\cdot)$ and thus play a_o? As the sole benefit of being organistic consists in overtaking the mechanistic incumbent, it is straightforward that the histories $\tilde{\Omega}_\tau$ correspond to the cases *where all the incumbents are mechanistic* (Figure 3). 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 (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 (4).

This 'aggressive' behaviour is the main difference with the preceding Section.

From Figure 3, 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):

$$V_{mm} = \mathrm{e}^{-t_m r}\pi_{mm}/(r+\theta) \quad \text{with} \quad \pi_{mm} = 1 - \lambda^{-1}. \tag{20}$$

If the firm decides to be organistic, we have:

$$V_{mo}(\tilde{\Omega}_\tau) = \mathop{\mathrm{E}}_{\eta}\left(\int_{\tau+t_o}^{\tau_1+t_m} \mathrm{e}^{-rs}\pi_{mo}^{n}\mathrm{d}s + \int_{\tau_1+t_m}^{\tau_2+t_m} \mathrm{e}^{-rs}\pi_{mo}^{n-1}\mathrm{d}s + \ldots + \int_{\tau_n+t_m}^{\eta} \mathrm{e}^{-rs}\pi_{mo}\mathrm{d}s\right). \tag{21}$$

The payoff $V_{mo}(\tilde{\Omega}_\tau)$ depends of the sequence of incumbents $(\tau_1, \ldots, \tau_n)$. The more $(\tau_1, \ldots, \tau_n)$ 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 favourable to becoming organistic occurs when an infinity of mechanistic incumbents bought patents just before the firm does. Parameters verifying $V_{mo}(\tilde{\Omega}) \leq V_{mm}$ 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 $\{\tau_1 = \tau_2 = \cdots = \tau_n = \tau\}$ 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:

$$\tilde{V}_{mo}^{n+1} = \underbrace{\int_{t_o}^{t_m} \mathrm{e}^{-rs}\pi_{mo}^{n+1}\mathrm{d}s}_{\text{overtaking benefits}} + \mathop{\mathrm{E}}_{\eta}\left(\int_{t_m}^{\eta} \mathrm{e}^{-rs}\pi_{mo}\mathrm{d}s\right). \tag{22}$$

Computations show that:

$$\tilde{V}_{mo}^{n+1}(\theta) = \frac{\mathrm{e}^{-t_o.r} - \mathrm{e}^{-t_m.r}}{r}\left(1 - \frac{a_o}{\lambda^{n+1}a_m}\right) + \mathrm{e}^{-t_m.r}\frac{\pi_{mo}}{r+\theta}. \tag{23}$$

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 (21) with respect to $(\tau_1, \ldots, \tau_n)$ guaranties that this condition is equivalent to:

$$\lim_{n\to\infty} \tilde{V}^n_{mo} \leq V_{mm}(\theta). \tag{24}$$

Taking the limit in (23) and using (20), we get that the condition (24) is equivalent to:

$$\theta \leq r\left\{\frac{a_m/a_o - 1}{\lambda[\mathrm{e}^{(t_m-t_o)r} - 1]} - 1\right\}. \tag{25}$$

Given assumption (A1), condition (25) is equivalent to:

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

Appendix B: Controls in Tables 1 and 2

The regressions presented in Tables 1 and 2 are made with data from the REPONSE survey, which we exploited under an agreement with the Ministry of Industry. Besides the main variables – described in the text – we included controls, that we thought would capture best the underlying firm heterogeneity that could be related with the adoption of new organisational practices. These controls are especially important, since our dataset is a cross section, which makes fixed effects estimation unfeasible. This is why we added 16 industry dummies. The additional variables proxy for whether the firm is sufficiently 'sophisticated', which would make it sensitive to the diffusion of new organisational practices (listed, multi-establishment, large, skill composition, export). 'Unionisation' proxies for the extent to which employees may block the adoption of these practices. 'Share of main client in sales' proxies for the competitive pressure the firm is put under, which would encourage it to adopt the new practices.

Here is the list of the controls.

- *Multi-establishment firm*: dummy that takes the value 1 if the establishment is owned by a firm that has at least two establishments.
- *Quoted firm*: the establishment is owned by a firm that is quoted on a stock market.
- *Workforce composition*: proportion of workers, clerks, technicians and managers
- *Size*: employment size of the establishment according to 5 categories ($20 \leq 50, 50 \leq 100, 100 \leq 500, 500 \leq 1000, >1000$)
- *Unionisation*: dummy that is equal to 1 if there is a union's representative in the establishment.
- *Dynamism*: 5 classes for the dynamism of establishment activity during the past three years according to the employer (stagnant, declining, strongly declining, growing, strongly growing)
- *Geographical market*: the establishment operates in a local, regional, national or global market.
- *Share of the main client in sales*: 5 classes (non-significant – e.g. retail trade shop – less than 10%, less than 25%, less than 50%, more than 50%)
- *Dummies* for 16 industries according to the French industrial classification NAF 16.

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