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MONOPOLIES LIFE CYCLE, BUREAUCRATIZATION AND SCHUMPETERIAN GROWTH

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ABSTRACT

Monopolies Life Cycle, Bureaucratization, and Schumpeterian Growth*

This Paper analyses the link between the internal organization of firms, their individual life cycle and the whole process of macroeconomic growth. We present a Schumpeterian growth model in which firms face dynamic agency costs. These agency costs are due to the formation of vertical collusions within the organization. To respond to the opportunity of internal collusion, firms go through a whole life cycle, becoming more bureaucratized and less efficient over time. This bureaucratization affects both the intertemporal distribution of profits in a given sector and the distribution of output across sectors. In a general equilibrium model, bureaucratization has two effects: a profitability effect on the return of innovation and a reallocation effect on the skilled labour market. First, we analyse the existence and properties of stationary equilibrium growth. Second, we endogenize the transaction costs of side-contracting and show how the growth rate depends on various organizational parameters of firms.

JEL Classification: D92, L22, O40
Keywords: bureaucratization, dynamic collusion, internal organization of the firm, Schumpeterian growth

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NON-TECHNICAL SUMMARY

How does the internal organization of firms affect the set of social relationships within the firm and their life cycles? Is there a link between the life cycle process through which individual firms evolve and the whole path of macroeconomic growth? More precisely, how does the intertemporal distribution of profits and outputs of those firms affect growth? These questions are crucial if we want to understand better the role of organizations and, more broadly, of institutions in the growth process.

This Paper is a first attempt to analyse the interplay between the growth process and the internal organization of firms and, more specifically, the dynamic agency problems between owners of those firms and their management. Our main goal is to understand how the bureaucratization of large monopoly firms involved in the growth process affects the rate of creative destruction in the economy.

To achieve this goal, we blend together a Schumpeterian model of economic growth and a simple agency model with vertical collusion. This model allows us to analyse how the process of creative destruction generates an endogenous economic selection mechanism across firms and it allows us to derive organizational behaviour in the distribution of surviving firms.

As in standard Schumpeterian models, a final competitive sector uses intermediate goods produced by monopolies. The perspective of monopoly profits in these intermediate sectors creates the incentives for the R&D sectors to innovate. The profitability of those monopolies coupled with the positive externality associated with the public good nature of social knowledge is therefore the fundamental engine of growth. Contrary to standard neoclassical growth models (both exogenous and endogenous), however, we open the black box of the firm. Monopolistic firms are viewed as three-tier hierarchies involving owners, supervisors and managers. In this framework, owners allocate resources within the firm subject to the incentive constraints that arise when managers have a better knowledge of the firm's market demand, and can get information rent from this knowledge. But owners also use monitoring structures (supervisors) to reduce this informational gap with the firms' managers. Departing from most of the literature on collusion in organizations, the quality of the colluding relationship between supervisors and managers is not constant. Instead, transaction costs of side-contracting within the firm must be linked to the prospects that members of a collusion have to continue to exchange favours in the future if the firm goes on, i.e. if there is no innovation, making the firm's technology obsolete. Transaction costs of side-contracting decrease over time, capturing Olson's intuition that collusions become more efficient over the life of a given firm. The older this firm, the greater the burden of collusion it faces.

The main contribution of our Paper is to highlight the role of the dynamics of transaction costs at the firm level on the whole growth process. As noticed by several sociologists, the stability of the environment in which the firm evolves is the fundamental glue of collusions inside organizations. When the process of creative destruction in a society does not exert its clumping effect, vertical cliques within the firm become more efficient and transaction costs of collusion have enough time to decrease. The threat of facing more collusion over the life of a monopoly makes its owners eager to move incentive schemes towards being less and less powered over time. The firm becomes increasingly bureaucratized during its lifetime. This bureaucratization significantly impedes the achievement of efficiency within monopolized sectors since it implies an inefficient use of information. As a result, the profitability of the intermediate sectors falls. This reduces the R&D sectors' incentives to innovate. Growth is slowed down by the agency problems faced within intermediate sectors, and, in turn, there is little creative destruction in the economy.

On the other hand, when the rate of innovation is greater the process of creative destruction fully exerts its disciplinary effect. Vertical cliques have less opportunities to form. Collusion does not have enough time to really affect the allocation of resources since firms die on average before bureaucratization becomes significant. The selection process is biased towards less bureaucratized organizational behaviour. In turn, the profitability of the intermediate sectors is greater and pushes up the R&D sectors' incentives to innovate. Growth is reinforced.

We show that bureaucratization has a double impact in a general equilibrium model. First, since the bureaucratization of intermediate sectors implies a decreasing path of productivity-adjusted profits, it affects the incentives of the R&D sectors. Those incentives are greater when what matters the most in evaluating the firm's intertemporal profit is the beginning of the profits sequence, i.e. when firms are not too bureaucratized. Second, in a stationary equilibrium the distribution of outputs across sectors replicates exactly the intertemporal distribution of output in a given sector. Hence, as the bureaucratization of a firm in a given sector is more pronounced, the average output across sectors is reduced and more resources become available in the R&D sectors: a reallocation effect.

Analysing the precise interaction between those two effects of bureaucratization, we prove the existence of at least one stationary equilibrium growth under the sole assumption that the transaction costs of side-contracting are decreasing over time. Moreover, asymmetric information and collusion are shown to affect the growth rate only because of this time dependency of transaction costs which thus appears a crucial feature of our modelling.

Because of the macroeconomic externality generated by social knowledge, the negative impact of bureaucratization on the incentives to innovate may be amplified. Since less innovation occurs at the level of each individual sector, there is less accumulation of social knowledge and productivity growth diminishes. This effect reduces even further the profitability of intermediate sectors and the incentives to innovate in each research sector. Multiple equilibria may then emerge, some with a high growth rate, intense creative destruction and little bureaucratization, others with slow growth, weak creative destruction and bureaucratized monopolistic firms.

Our results are cast as much as possible under the sole assumption, consistent with Olson's observation, that transaction costs of collusion decrease over the whole life cycle of the firm, thereby implying its bureaucratization. Hence, these results are consistent with several possible theories of transaction costs as long as this monotony is maintained. To get more insights on the impact of those dynamic agency costs on the macroeconomy we present finally a microeconomic theory showing how an organization goes through a life cycle and gets more bureaucratized over time as a response to the threat of self-enforceable collusions. We show how the stationary equilibrium growth rate depends on parameters associated with the internal organization of firms (like control mechanisms and information processing technologies). In particular, any change in information and monitoring technologies that increases the opportunities for collusion has an impact on macroeconomic growth which may be negative when the profitability effect dominates and positive when the reallocation effect dominates.

1 Introduction

Starting with Schumpeter (1911), economists have defended the view that there exists a process of creative destruction by which new entrepreneurs displace old tired incumbents. For instance, Marshall (1920, p.263) has further argued that *"as with the growth of trees, so was it with the growth of businesses [..] which often stagnate, but do not readily die. [..] Nature still presses on the private business by limiting the length of the life of its original founders, and by limiting even more narrowly that part of their lives in which their full faculties retain full vigour."* The basic Schumpeterian models of Aghion and Howitt (1992, 1998) and Grossman and Helpman (1992) can be viewed as giving an elegant rationale to the process of creative destruction. However, contrary to what is postulated in these latter models, what turn of the century economists had in mind was not a model where incumbent firms had a stationary life but, instead, a model where firms would go through a whole life cycle, getting less efficient over time before being replaced by new entrants on the market. Implicit behind this argument is the idea that older firms or institutions face some sort of organizational slacks which increase over time. This point is also pointed out by Olson (1982, p.42) who forcefully argues, in his celebrated book *The Rise and Decline of Nations*, that *"Stable Societies with unchanged boundaries tend to accumulate more collusions and organizations for collective action over time"*. Starting from this casual observation, Olson describes a dynamics of the economy which emphasizes that collusion has detrimental consequences for growth.

Several questions emerge from all these observations. Given that the organizational scleroris striking individual firms is due to collusive behaviors at the firm's level, how does the internal organization of those firms affect the set of social relationships within the firm and their life cycle? Is there a link between the life cycle process through which individual firms evolve and the whole path of macroeconomic growth? More precisely, how do the intertemporal distribution of profits and outputs of those firms affect growth? These questions are crucial ones if we want to understand better the role of organizations and, more broadly of institutions, in the growth process. Until now, almost no effort has been devoted to give formal answers to these issues. This lack of formal work is probably better explained by the difficulty one encounters at describing the internal structure of the firm at a relatively detailed microeconomic level, allowing for the analysis of agency costs, while at the same time, integrating these considerations into a general equilibrium growth framework.

This paper is a first attempt to analyze the interplay between the growth process and the internal organization of firms and, more specifically, the dynamic agency problems between owners of those firms and their management. Our main goal is to understand how the bureaucratization of large monopoly firms involved in the growth process affects the rate of creative destruction in the economy. To achieve this goal, we will blend together three different incomplete strands in the economic literature which give only partial answers to this question. First, the "Olsonian" perspective on growth leaves unsettled the issue of why more collusions tend to develop inside organizations over time and how these collusions can really affect the growth process.

Second, the recent microeconomic literature on collusion in organizations starting with Tirole (1986, 1992) has underscored how bureaucratic rules represent in fact optimal responses to the emergence of collusions inside the firm. Following industrial sociologists,[1] this literature recognizes that supervisors and managers are at a nexus of commonly known information. They may take advantage of this collective informational advantage to promote their own objectives against those of the owners of the firm.[2] As a response to the possibility of those collective manipulations of information, owners tilt incentive schemes towards relatively bureaucratic rules which are less sensitive to information and which leave few discretion to supervisors. This collusion literature has been developed in a partial and, most often, static equilibrium framework and, therefore, cannot tell us anything about the dynamics the economy as a whole. In particular it leaves open the question of how collusions may interact at the macroeconomic level to reduce growth.

Finally, the so called literature on *"population ecology"*[3] investigates the evolution of the whole population of organizations. The emphasis here is on describing how changes in the firms' external environment affect organizational behaviors through selective forces at the population level. This approach offers an interesting link between the macro side of the economy and the micro behaviors within firms, most noticeably those concerning the adoption of routinized behaviors. As our paper, this literature is interested in the distribution of firms at different points of time in the selection process. However, this perspective is incomplete since it does not provide clear foundations to the process of economic selection. Also, it does not take either into account the aggregate potential feedback effects of the distribution of organizational behaviors on the dynamics of the external environment itself. Hence, it misses the macroeconomic implications of collusion which was illustrated by Olson.

In order to integrate the disparate insights of these three trends of the literature, we consider a Schumpeterian model of economic growth along the lines of Aghion and Howitt

[1] Dalton (1959) and Crozier (1962).

[2] The supervisor may manipulate or delay the audit he performs to assess the manager's performances. In exchange, the latter may bribe him or give him some in-kind transfers.

[3] See Hannan and Freeman (1977, 1989).

(1992, 1998) and Grossman and Helpman (1992) in which we embed a simple agency model with vertical collusion à la Tirole (1986, 1992). This model allows us to analyze how the process of creative destruction generates an endogenous economic selection mechanism across firms and to derive organizational behaviors in the distribution of surviving firms.

As in standard Schumpeterian models, a final competitive sector uses intermediate goods produced by monopolies. The perspective of monopoly profits in these intermediate sectors creates the incentives of the R&D sectors to innovate. The profitability of those monopolies coupled with the positive externality associated to the public good nature of social knowledge is therefore the fundamental engine of growth. However, contrary to standard neoclassical growth models (both exogenous and endogenous ones), we open the black box of the firm. Monopolistic firms are viewed as three-tier hierarchies involving owners, supervisors and managers. In this framework, owners allocate resources within the firm subject to the incentive constraints which arise when managers have a better knowledge on the firm's market demand and get information rent from this knowledge. But also owners use monitoring structures (supervisors) to reduce this informational gap with the firms' managers. Departing from most of the literature on collusion in organizations, the quality of the colluding relationship between supervisors and managers is not constant. Transaction costs of side-contracting decrease over time, capturing Olson's intuition that collusions become more efficient over the life of a given firm. The older this firm, the greater the burden of collusion it faces.

The main contribution of our paper is to highlight the role of the dynamics of transaction cost at the firm level on the whole growth process. As noticed by several sociologists, the stability of the environment in which the firm evolves is the fundamental glue of collusions inside organizations.[4] When the process of creative destruction in a society does not exert its clumpsering effect, vertical cliques within the firm become more efficient and transaction costs of collusion have enough time to decrease.[5] The threat of facing more collusion over the life of a monopoly makes its owners eager to move incentive schemes towards being less and less powered over time. The firm becomes increasingly bureaucratized during its lifetime. This bureaucratization impedes significantly the achievement of efficiency within monopolized sectors since it implies an inefffficient use of information. As a result, the profitability of the intermediate sectors falls. This reduces the R&D sectors incentives to innovate. Growth is slowed down by the agency problems faced within

[4]See Pfeffer (1983) and Granovetter (1992) for a discussion on the role of turnover of the labor force and inside efficiency and bureaucratization of firms.

[5]In Olson (1982)'s vocabulary, collusions *"have more opportunities to emerge."* In the vocable of "population ecology," social selection forces are biased towards higher survival rates of organizations with vertical collusion.

intermediate sectors, and, in turn, there is little creative destruction in the economy. On the contrary, when the rate of innovation is greater, the process of creative destruction fully exerts its disciplinary effect. Collusion does not have enough time to really affect the allocation of resources since firms die on average before bureaucratization becomes significant. The selection process is biased towards less bureaucratized organizational behaviors. In turn, the profitability of the intermediate sectors is greater and pushes up the R&D sectors incentives to innovate. Growth is reinforced.

The key to understand our results is to see that bureaucratization has a double-impact in a general equilibrium model. First, since the bureaucratization of intermediate sectors implies a decreasing path of productivity-adjusted profits, it affects the incentives of the R&D sectors. Those incentives are greater when what matters the most in evaluating the firm's intertemporal profit is the beginning of the profits sequence, i.e., when firms are not too much bureaucratized. Second, in a stationary equilibrium, the distribution of outputs across sectors replicates exactly the intertemporal distribution of output in a given sector. Hence, as the bureaucratization of a firm in a given sector is more pronounced, the average output across sectors is reduced and more resources become available in the R&D sectors: a reallocation effect.

Analyzing the precise interaction between those two effects of bureaucratization, we prove the existence of at least one stationary equilibrium growth under the sole assumption that the transaction costs of side-contracting are decreasing over time. Moreover, asymmetric information and collusion are shown to affect the growth rate only because of this time-dependency of transaction costs which appears thus a crucial feature of our modeling.

As in all Schumpeterian models, social knowledge is a public good. As a result of this macroeconomic externality, the negative impact of bureaucratization on the incentives to innovate may be amplified. Since less innovation occurs at the level of each individual sector, there is less accumulation of social knowledge and productivity growth diminishes. This effect reduces even further the profitability of intermediate sectors and the incentives to innovate in each research sector. Multiple equilibria may then emerge. Some with a high growth rate, intense creative destruction and little bureaucratization, others with slow growth, weak creative destruction and bureaucratized monopolistic firms.

Our results are cast as much as possible under the sole assumption, consistent with Olson (1982)'s observation, that transaction costs of collusion decrease over the whole life cycle of the firm implying, thereby, its bureaucratization. Hence, these results are consistent with several possible theory of transaction costs as long as this monotonicity is maintained. To get more insights on the impact of those dynamic agency costs on the macroeconomy, we borrow from Martimort (1999) a theory showing how an organization goes through a life cycle and gets more bureaucratized over time as a response to the threat of self-enforceable collusions based on trigger strategies à la Abreu (1986). Armed with this theory, we show how the stationary equilibrium growth rate depends on parameters associated to the internal organization of firms (like control mechanisms and information processing technologies). In particular, any change in information and monitoring technologies which increases the opportunities for collusion has an impact on macroeconomic growth which may be negative when the profitability effect dominates and positive when the reallocation effect dominates.

This paper belongs to a small burgeoning literature trying to link agency considerations, the internal organization of the firm and the growth process. In a model with horizontally differentiated products, Acemoglu and Zilibotti (1999) argue that the performances of competitors may provide useful information to improve incentives within a given firm. As in our model, the equilibrium growth rate is affected by the firms profitability which, in turn, depends on the spectrum of products already available. Aghion, Dewatripont and Rey (1999) analyze a model where the threat of bankruptcy forces conservative managers to speed up the adoption of new technologies to remain competitive on the product market. Thesmar and Thoenig (1998) endogenize the choice of firms' organizational structures in a Schumpeterian growth. They emphasize how these structures affect the tradeoff between productivity and delay of adoption in new technologies and derive implications for wage inequality and growth. Martimort and Verdier (2000) is the closest paper to the present one. There, we analyze a static model of collusion within the firm. Contrary to the present paper, transaction costs of side-contracting are not endogenized through the dynamics of the collusive relationships but by allowing colluding partners to invest part of their initial endowment of skilled labor to improve the efficiency of side-contracting. Because this latter paper takes a static perspective, it cannot account for the life cycle of the firm and draw the implications of the existence of a whole intertemporal distribution of profits for the growth rate of the economy.

At a broader level, our paper is also linked to the subset of the agency literature which, following Hart (1983), investigates the impact of the external environment on agency costs. These papers discuss the one-sided causality from static market competition to agency costs arguing[6] that more competition may reduce agency costs. Two major differences with our own work should be stressed. First, these papers obviously view competition as a static phenomenon and are not interested in its Schumpeterian perspective.[7] Second, our

[6] See Schmidt (1997) for a recent contribution along these lines.

[7] A noticeable exception is Selten (1986) who offers an "X-inefficiency" model in which the dynamics of slacks is exogenously specified.

analysis stresses the reverse causality and argues that organizational forms and agency costs impact, in turn, on the replacement of incumbent firms and the degree of dynamic competition.

Section 2 describes both the macroeconomic and the microeconomic sides of the economy. Section 3 presents a model in which the monopolies life cycle is postulated by specifying a declining dynamics of transaction costs. As a benchmark, this section derives also the growth rate of the economy when transaction costs of side-contracting are not time-dependent. Section 4 derives the existence and main properties of the stationary rate of growth under the sole assumption that those transaction costs decreases over time. We obtain there simple conditions under which bureaucratization pushes up or slows down the growth process. Section 5 goes further by deriving endogenous transaction costs and in exhibiting their time-dependency. Coming back on the analysis of the growth rate distortions due to agency costs, we then derive also several implications of the endogenous relationship between the rate of growth and parameters characterizing the internal organization of the firm. Section 6 concludes. Proofs are relegated to an Appendix.

2 The Model

Our model has two building blocks. The first one is a standard Schumpeterian model à la Aghion and Howitt (1992, 1998).[8] It represents the macroeconomic side of the economy. The second building block is a microeconomic modelling of the agency problem taking place within the monopolistic firms populating this macroeconomic environment.

2.1 The Macroeconomic Side

We abstract completely from capital accumulation. Time is indexed by $t \in \{0, +\infty\}$.

2.1.1 Preferences

The economy is populated by a continuous mass L of individuals with linear intertemporal preferences:

$$u(y) = \sum_{t=0}^{\infty} \frac{1}{(1+r)^t} y_t \tag{1}$$

where $y = \{y_t\}_{t \geq 0}$ the vector of consumptions. r is the interest rate which is exogenously given.[9] Each of these individuals is endowed with one unit flow of skilled labor.

[8] See also Grossman and Helpman (1992).

[9] It is also equal to the psychological discount rate of those risk neutral agents.

2.1.2 Technologies

• **Final Sector**: There is only one final consumption good which is produced from a continuum of intermediate goods indexed on the unit interval.[10] More precisely, date t output in the final good sector is:

$$y_t = \int_0^1 y_{it} di$$

where

$$y_{it} = A_{it}\beta_{it}x_{it}^{\alpha} \quad (\alpha \in [0,1[) \tag{2}$$

is the flow of final good which can be produced using a quantity x_{it} of intermediate good i at date t.

The parameter A_{it} is the *"fundamental"* productivity of the latest generation of intermediate good i. The overall productivity of this sector is also affected by the realization of some random shock β_{it}. These shocks are independently distributed over time and across sectors according to the same common knowledge distribution on the discrete support $\{\underline{\beta}, \bar{\beta}\}$ ($\Delta\beta = \bar{\beta} - \underline{\beta} > 0$ is the spread of the uncertainty) with respective probabilities $1 - \nu$ and ν. β_{it} captures the intrinsic uncertainty on the quality of the match between the intermediate sector i and the final good technology. $\beta_{it} = \bar{\beta}$ (resp. $= \underline{\beta}$ when there is a good match.

• The final sector has perfect knowledge of the parameters β_{it}. This sector is perfectly competitive and its demand for each intermediate good writes thus as:

$$p_{it} = \alpha A_{it}\beta_{it}x_{it}^{\alpha-1} \tag{3}$$

where p_{it} is the price of good i at date t.

• **Intermediate Sectors**: Each intermediate good is produced by a monopoly M_i.[11] This firm holds a patent of the latest generation of good i. To produce one unit of intermediate good i requires one unit of skilled labor.

Since the productivity of the final sector is random, this monopolist faces, at each date t, an uncertain demand for its good which depends on the realization of β_{it}.

• **Research Sectors**: There are one research sector for each intermediate good. R&D firms in each sector compete to discover the next generation of good i. The arrival of innovations in a given sector follows a Poisson process. An innovation appears with probability $\phi(n_{it}) \in [0,1]$ where n_{it} is the amount of skilled labor devoted to research in

[10] The assumption that there is a continuum of goods is important in our characterization of a stationary equilibrium.

[11] q is large enough so that a monopoly does not have to undertake limit pricing to capture its market's demand

this sector. As n_{it} increases, the probability of an innovation increases but at a decreasing rate: $\phi'(n) > 0$ and $\phi''(n) < 0$ with the Inada conditions $\phi'(0) = \infty$ and $\phi'(L) = 0$. For technical reasons, we also assume that $\phi''(n)\phi(n) + (\phi'(n))^2 \leq 0$ for all n.

By innovating in sector i, a R&D firm acquires the leading-edge technology (society knowledge) whose productivity parameter is given by $A_t^{\max} = max A_{it}$. Each time a fraction ϕ of firms innovate, this leading-edge technology jumps upwards by an increment $\phi q + (1 - \phi)$ where $q > 1$.

With a continuum of intermediate sectors, the Law of Large Numbers applies and ensures that, in a symmetric and stationary equilibrium where all research sectors use the same amount of skilled labor n^* at each date, there is always a fraction $\phi(n^*)$ of firms innovating at each date t. Along such a path, the leading-edge technology obeys to the following difference equation:

$$A_{t+1}^{\max} - A_t^{\max} = \phi(n^*)(q-1)A_t^{\max}. \tag{4}$$

When more firms innovate at the same time, the upwards jump of the leading-edge technology is greater. The evolution of the leading-edge technology is thus affected by a macroeconomic positive externality due the public good nature of society knowledge. Note also that the fundamental productivity parameter in a given sector i, A_{it}, moves discontinuously at the time of innovation in this sector if it jumps ahead several steps to reach the new leading-edge technology. Because of this, the quality of a new generation of product in a given sector benefits from this technological spill-over accross sectors.

2.2 The Microeconomic Side

We now open the black box of the internal organization of the monopolies in the intermediate sectors.

2.2.1 Internal Organization of the Firms

• As said above, producing one unit of intermediate good i requires one unit of skilled labor used in a production department. It requires also to establish a sales department. The manager of the sales department is privately informed on β_{it} the quality of the match between the intermediate i and the final good. Instead, owners remain uninformed. A supervisor may thus be used to fill this informational gap. A monopoly can thus be viewed as a large firm having a hierarchical structure with on top his owners, in the middle layer a supervisor, and at the bottom a production and a sales departments.

• Consider a firm starting to be a monopoly at date t. At date $t + \tau$, the manager receives the sales proceeds $p_{i(t+\tau)}x_{i(t+\tau)} = \alpha A_{i(t+\tau)}\beta_{i(t+\tau)}x_{i(t+\tau)}^{\alpha}$ and gives back some dividends

$T_{i(t+\tau)}$ to the owners. The manager's intertemporal utility writes thus as:

$$\sum_{\tau=0}^{\infty} \frac{\prod_{l=0}^{\tau}(1-\phi(n_{i(t+l)}))}{(1+r)^{\tau}}(\alpha A_{i(t+\tau)}\beta_{i(t+\tau)}x^{\alpha}_{i(t+\tau)} - T_{i(t+\tau)}) \quad (5)$$

where $\prod_{l=0}^{\tau}(1-\phi(n_{i(t+l)}))$ is the probability that the firm borne at date t remains a monopoly up to date $t+\tau$.

• At each date, the supervisor may learn an informative signal $\sigma_{i(t+\tau)}$ on the realization of $\beta_{i(t+\tau)}$. The monitoring technology is such that $\bar{\beta}$ is learned with a conditional probability ϵ. Otherwise, nothing is learned. This gives the following unconditional probabilities:

$$\sigma_{i(t+\tau)} = \begin{cases} \bar{\beta} \text{ with probability } \nu\epsilon \\ \emptyset \text{ with probability } 1-\nu\epsilon. \end{cases}$$

$\sigma_{i(t+\tau)}$ is a piece of *hard information*. The knowledge of $\bar{\beta}$ can be concealed to the owners but can never be manipulated by the supervisor.

The supervisor receives wages $S_{i(t+\tau)}$ from the owners of the firm. His intertemporal utility is thus:

$$\sum_{\tau=0}^{\infty} \frac{\prod_{l=0}^{\tau}(1-\phi(n_{i(t+l)}))}{(1+r)^{\tau}} S_{i(t+\tau)}. \quad (6)$$

• Owners of a patent for good i starting at date t maximize their intertemporal discounted profits from that date on:

$$V_{it} = \sum_{\tau=0}^{\infty} \frac{\prod_{l=0}^{\tau}(1-\phi(n_{i(t+l))}))}{(1+r)^{\tau}} \Pi_{i(t+\tau)} \quad (7)$$

where $\Pi_{i(t+\tau)} = T_{i(t+\tau)} - S_{i(t+\tau)} - w_{t+\tau}x_{i(t+\tau)}$ and $w_{t+\tau}$ are respectively the firm's profit and the wage of skilled labor at date $t+\tau$.

• There is a unit mass of supervisors (resp. sales department managers) available in this economy. Upon arrival of an innovation, there are as many supervisors and managers "dying" in old obsolete firms than new supervisors and managers hired in newly created monopolies. Hence the markets for managers and supervisors always clear.

• Supervisors and managers have an exogenously given reservation wage fixed to zero.[12]

[12] This assumption implicitly requires that supervisors and managers are not part of the skilled labor force. It is justified when a manager (or a supervisor) has to sunk some (not modeled) specific investment ex ante so that the labor market for managers (supervisors) and skilled labor are segmented. Let us now assume that those markets are not segmented. Then the overall size of the skilled labor market becomes $L+2$. Moreover, when supervisors and managers have a unit of skilled labor to offer, they can obtain a non-zero reservation wage $w_{i(t+\tau)}$. Since this non-zero reservation wage is fixed and does not depend on the knowledge of $\beta_{i(t+\tau)}$, it has no impact on the allocative distortions imposed by the incentive problem within the firm as it is well known from standard principal-agent theory. However, the net profit of the owners at each date is translated downwards by a constant term which is equal to $2w_{i(t+\tau)}$. This certainly affects the incentives to innovate of the R&D sector. However, the stream of productivity-adjusted profits would exhibit an intertemporal path which is quite similar to that obtained with a zero reservation wage. We conjecture that this should not disturb too much our analysis and that the impact of dynamic agency costs within the monopolies on their profitability and therefore on the growth rate of the economy remains the same.

2.2.2 Contracts

Because of the existing informational gap within the firm, owners have to rely on an incentive scheme to induce information revelation both from the manager because he is privately informed and from the supervisor because he may have an informative signal on the manager. From the Revelation Principle, there is no loss of generality in considering direct revelation mechanisms where both agents report truthfully their information to the owners.[13] An incentive scheme in a firm i born at date t is a whole vector of triplet

$$\{x_{i(t+\tau)}(\hat{\sigma}_{i(t+\tau)}, \hat{\beta}_{i(t+\tau)}), T_{i(t+\tau)}(\hat{\sigma}_{i(t+\tau)}, \hat{\beta}_{i(t+\tau)}), S_{i(t+\tau)}(\hat{\sigma}_{i(t+\tau)}, \hat{\beta}_{i(t+\tau)})\}_{\tau \geq 0}$$

where $\hat{\sigma}_{i(t+\tau)}$ (resp. $\hat{\beta}_{i(t+\tau)}$) is the supervisor's (resp. the manager's) report on the signal he has observed (resp. on his type). To make notations simpler, we denote the date $t+\tau$ component of this infinite dimensional vector by

$$C_{i(t+\tau)} = \left\{(\bar{x}_{i(t+\tau)}, \bar{T}_{i(t+\tau)}, \bar{S}_{i(t+\tau)}), (\underline{x}_{i(t+\tau)}, \underline{T}_{i(t+\tau)}, \underline{S}_{i(t+\tau)}), (\bar{x}^*_{i(t+\tau)}, \bar{T}^*_{i(t+\tau)}, \bar{S}^*_{i(t+\tau)})\right\}$$

where each triplet above is made of the output, the manager's transfer and the supervisor's wage in the respective states of nature $(\sigma_{it} = \emptyset, \beta_{it} = \bar{\beta})$ $(\sigma_{it} = \emptyset, \beta_{it} = \underline{\beta})$ and $(\sigma_{it} = \bar{\beta}, \beta_{it} = \bar{\beta})$. Note that these states of nature have respective probabilities $\nu(1-\epsilon), 1-\nu$ and $\nu\epsilon$.

Two features of this contract should be stressed. First, the agent's report is only used following an uninformative report from the supervisor, i.e., following $\hat{\sigma}_{it} = \emptyset$. Indeed, when $\hat{\sigma}_{it} = \bar{\beta}$ has been reported (and has also been observed since information is hard), there is no reason to use the manager's report since the state of nature is perfectly known by owners. Second, the contracts are not history dependent. Wages and output targets are only dependent on calendar time and reports on the current information learned by the supervisor and the manager.[14]

[13] See Myerson (1979).

[14] Allowing history-dependent contracts is useless both in the case where the supervisor and the manager do not collude and in the case where they collude with enforceable short-term side-contracts running for the current period. To see that, consider for instance the first case, repeated agency problems tell us that history is useful when the principal commits to different continuation payoffs for the agent according to the latter's current report of type. Indeed, incentive compatibility requires to have the agent bear some risk when he is risk-averse. Thereby, the cost of current incentive compatibility can be spread between the current period and the future of the relationship. This is no longer useful with risk-neutrality and the per period limited liability constraints that we consider below on (9), (10) and (11). The optimal history dependent contract without collusion is thus independent of the past history of reports and is just replicated by an history independent contract of the kind suggested in the text. The same argument goes through in the case of short-term enforceable collusive side-contracts running for each period separately (see Section 3 below). The only loss of generality may occur when collusion is self-enforceable. In this case, we will assume that the owners can commit to an intertemporal production plan, i.e., the sequence $\{x_{i(t+\tau)}(\cdot)\}_{\tau\geq 0}$ once they get their monopoly patent. However, they cannot commit to the wages needed

• **Incentive Compatibility and Participation Constraints**: Let us first assume that the supervisor has reported no informative signal at date $t+\tau$, i.e., $\hat{\sigma}_{i(t+\tau)} = \emptyset$. We denote the manager's information rents in each state of nature by

$$\bar{U}_{i(t+\tau)} = \alpha A_{i(t+\tau)} \bar{\beta} \bar{x}^{\alpha}_{i(t+\tau)} - \bar{T}_{i(t+\tau)}$$

and

$$\underline{U}_{i(t+\tau)} = \alpha A_{i(t+\tau)} \underline{\beta} \underline{x}^{\alpha}_{i(t+\tau)} - \underline{T}_{i(t+\tau)}.$$

We can now easily write the incentive compatibility constraint preventing a manager having observed a high realization of demand $\bar{\beta}$ to pretend it was instead a low realization $\underline{\beta}$:

$$\bar{U}_{i(t+\tau)} \geq \alpha A_{i(t+\tau)} \bar{\beta} \underline{x}^{\alpha}_{i(t+\tau)} - \underline{T}_{i(t+\tau)} = \underline{U}_{i(t+\tau)} + \alpha A_{i(t+\tau)} \Delta\beta \underline{x}^{\alpha}_{i(t+\tau)}.^{15} \tag{8}$$

We assume that the manager cannot be forced to a negative payoff in any single period because of a limited liability constraint.[16] Hence, we must have:

$$\underline{U}_{i(t+\tau)} \geq 0.^{17} \tag{9}$$

For the same reasons, the following constraints must also be satisfied:

$$\underline{S}_{i(t+\tau)} \geq 0, \tag{10}$$

and

$$\bar{S}_{i(t+\tau)} \geq 0. \tag{11}$$

When the supervisor has observed an informative signal, i.e., $\hat{\sigma}_{i(t+\tau)} = \bar{\beta}$, the manager is known having observed a high demand. We must again have:

$$\bar{U}^{*}_{i(t+\tau)} = A_{i(t+\tau)} \bar{\beta} \bar{x}^{*\alpha}_{i(t+\tau)} - \bar{T}^{*}_{i(t+\tau)} \geq 0. \tag{12}$$

and

$$\bar{S}^{*}_{i(t+\tau)} \geq 0. \tag{13}$$

to implement this production plan. As it will become clearer later on, this latter assumption plays an important role in describing how the firm responds to the threat of those self-enforceable collusions. See Martimort (1999) for further discussions of this assumption.

[15] It is standard to show that this incentive constraint is the only binding one at the optimum. The incentive constraint of a low demand manager is automatically satisfied.

[16] An alternative assumption is that the manager is infinitely risk-averse below zero wealth. Keeping the assumption that the manager is risk neutral, we are thus implicitly assuming there that the manager must consume all his current wealth and cannot save or borrow to change the nature of these per period limited liability constraints.

[17] When (9) and (8) are binding, it is easy to show that $\bar{U}_{i(t+\tau)} \geq 0$ so that the limited liability constraint of a $\bar{\beta}$ manager is automatically satisfied once the firm always produces a positive amount.

2.2.3 Collusion

To complete the description of the incentive problems faced by large bureaucratized firms, we assume that there is collusion between the supervisor and the manager lying at a nexus of commonly known information. Indeed, the supervisor has some discretionary power in revealing or not the manager's information when he has received an informative signal $\sigma_{i(t+\tau)} = \bar{\beta}$. He uses this power to extract some benefit from his close relationship with the manager.

By concealing this information to owners, the supervisor let the manager benefit from a strictly positive information rent $\bar{U}_{i(t+\tau)}$. In exchange, the manager gives up some bribes to his supervisor. These bribes take a monetary form in our model but they should more generally be viewed as a reduced form for the good social relationships which may establish on the work place or other in-kinds transfers.[18] If he instead reveals the informative signal to the owners, the supervisor ensures that this information rent can be fully captured by owners and that allocative distortion due to asymmetric information will be smaller. This creates the incentives of owners to prevent collusion which is detrimental to the firm.

Following Tirole (1986), we assume that all bargaining power in the side-contract is given to the supervisor. A priori, the full gain from collusion at a given date goes thus to the supervisor. This gain is the difference in information rents $\bar{U}_{i(t+\tau)} - \bar{U}^*_{i(t+\tau)}$ that can be pocketed by the manager when the supervisor hides an informative signal to the owners. In Section 3, we assume that collusive contracts are short-term running only for the current period and are enforceable. Section 5 relaxes this assumption.

As it has been suggested by Tirole (1986), the collusive activity nevertheless suffers from some deadweight-loss due to *transaction costs* of exchanging favors within the firm. When a side-transfer is made between the manager and the supervisor at date $t+\tau$, only a fraction $k(\tau) < 1$ is pocketed by the supervisor. The supervisor's benefit from colluding with the manager at date $t+\tau$ writes thus as:

$$k(\tau)(\bar{U}_{i(t+\tau)} - \bar{U}^*_{i(t+\tau)})$$

where $k(\tau)$ is the efficiency of side-contracting at date $t+\tau$. For the time being, we follow the earlier literature on collusion in organizations and assume that the function $k(\cdot)$ is exogenously given. Without loss of generality, we will thus assume that the efficiency of side-contracting explicitly depends on the age of the firm. $k(\tau)$ denotes therefore this efficiency in a firm having already lived for τ periods. When k gets larger, collusion is more efficient and is more harmful to the organization.

[18] See Gouldner (1954) for the sociological analysis of these reciprocal exchanges.

To be consistent with the theory that we present later in Section 5, one can think of $1-k$ as representing the deadweight-loss associated with the lack of enforceability of the side-contract between the supervisor and the manager. A large value of k means then that collusion can be quite easily enforced within the organization. More generally, k can be viewed as an index of the amount of vertical trust embodied in the supervisor-manager relationship.

To exhaust the scope for collusion, the supervisor must receive a wage large enough so that he prefers revealing an informative signal $\sigma_{it} = \bar{\beta}$ to the owners rather than concealing evidence and sharing the corresponding information rent with the manager. An incentive mechanism prevents collusion between the supervisor and the manager when the following *collusion-proofness constraint* is satisfied:

$$S^*_{i(t+\tau)} - \bar{S}_{i(t+\tau)} \geq k(\tau)(\bar{U}_{i(t+\tau)} - \bar{U}^*_{i(t+\tau)}). \tag{14}$$

3 The Dynamics of Transaction Costs

In this section, we investigate how the dynamics of transaction costs for collusive behavior affects the growth rate of the economy.

3.1 Optimal Collusion-Proof Contract

As a benchmark, we find the optimal *collusion-proof contract* implemented by the owners of monopoly i when they get a patent from date t on.

With history independent contracts, incentive, collusion-proofness and all limited liability constraints are written period per period. The optimal collusion-proof contract is thus obtained by adding altogether the solutions to one-shot incentive problems at each different dates $t+\tau$.

Using the definitions of the manager's information rents to express the transfers $T_{i(t+\tau)}$ as a functions of these rent into the owners' objective function, the one-shot incentive problem at date $t+\tau$ writes thus as:

$$\begin{aligned}
&\max_{C_{i(t+\tau)}} \nu\epsilon(\alpha A_{it}\bar{\beta}\bar{x}^{*\alpha}_{i(t+\tau)} - w_{t+\tau}\bar{x}^*_{i(t+\tau)} - \bar{U}^*_{i(t+\tau)} - \bar{S}^*_{i(t+\tau)}) \\
&+\nu(1-\epsilon)(\alpha A_{it}\bar{\beta}\bar{x}^{\alpha}_{i(t+\tau)} - w_{t+\tau}\bar{x}_{i(t+\tau)} - \bar{U}_{i(t+\tau)} - \bar{S}_{i(t+\tau)}) \\
&+(1-\nu)(\alpha A_{it}\underline{\beta}\underline{x}^{\alpha}_{i(t+\tau)} - w_{t+\tau}\underline{x}_{i(t+\tau)} - \underline{U}_{i(t+\tau)} - \underline{S}_{i(t+\tau)})
\end{aligned}$$

subject to constraints (8) to (14).

The following proposition describes the standard structure of the optimal collusion-proof contract in this one-shot problem.

Proposition 1 *: The optimal collusion-proof contract offered by a monopoly born at date t in sector i is such that the constraints (8) to (14) are all binding. Hence, the manager's information rent is positive only when $(\sigma_{i(t+\tau)} = \emptyset, \beta_{i(t+\tau)} = \bar{\beta})$:*

$$\bar{U}_{i(t+\tau)} = \alpha A_{i(t+\tau)} \Delta\beta \underline{x}^{\alpha}_{i(t+\tau)}. \tag{15}$$

The supervisor gets a positive wage only when $(\sigma_{i(t+\tau)} = \bar{\beta})$:

$$\bar{S}^{*}_{i(t+\tau)} = k(\tau)\alpha A_{i(t+\tau)} \Delta\beta \underline{x}^{\alpha}_{i(t+\tau)}. \tag{16}$$

Other features of the contract are:

- *Outputs are not distorted with respect to the complete information case when $(\sigma_{i(t+\tau)} = \bar{\beta})$ and $(\sigma_{i(t+\tau)} = \emptyset, \beta_{i(t+\tau)} = \bar{\beta})$,*

$$\bar{x}_{i(t+\tau)} = \bar{x}^{*}_{i(t+\tau)} = \left(\frac{w_{t+\tau}}{\alpha^2 \bar{\beta} A_{it}}\right)^{\frac{1}{\alpha-1}}; \tag{17}$$

- *Ouput is downwards distorted with respect to the complete information monopoly output when $(\sigma_{i(t+\tau)} = \emptyset, \beta_{i(t+\tau)} = \underline{\beta})$,*

$$\underline{x}_{i(t+\tau)} = \left(\frac{w_{t+\tau}}{\alpha^2 \underline{\beta}(\tau) A_{it}}\right)^{\frac{1}{\alpha-1}} \tag{18}$$

  where

$$\underline{\beta}(\tau) = \underline{\beta} - \frac{\nu}{1-\nu}\Delta\beta\left(1 - \epsilon + \epsilon k(\tau)\right) < \underline{\beta}. \tag{19}$$

- *Average output at date $t+\tau$ in sector i is given by:*

$$X_{i(t+\tau)} = \left(\frac{w_{t+\tau}}{\alpha^2 \bar{\beta} A_{it}}\right)^{\frac{1}{\alpha-1}} \left(\nu + (1-\nu)\left(\frac{\underline{\beta}(\tau)}{\bar{\beta}}\right)^{\frac{1}{1-\alpha}}\right). \tag{20}$$

- *Average profit at date $t+\tau$ is given by:*

$$\Pi_{i(t+\tau)} = w_{t+\tau} X_{i(t+\tau)}. \tag{21}$$

Asymmetric information makes costly the implementation of output that the monopoly would choose under complete information. To make the rent-production allocation of a low-demand manager less attractive to a high-demand manager, owners must reduce output in state $(\sigma_{i(t+\tau)} = \emptyset, \beta_{i(t+\tau)} = \underline{\beta})$ below its complete information value. This reduces the costly information rent of a high demand manager and the incentive compatibility constraint (8) is relaxed.

Moreover, reducing the information rent $\bar{U}_{i(t+\tau)}$ also diminishes the prospects for collusion between the supervisor and the manager once the former has observed an informative signal. The collusion-proofness constraint (14) is also relaxed. The benefits of reducing the size of activity increases when $k(\cdot)$ gets larger. More efficient side-contracting calls for more output distortions, less powerful incentives and therefore less information rents for a high demand manager. The supervisor is given less discretion as $k(\cdot)$ increases. The optimal contract looks more like a bureaucratic rule leaving few discretion to the supervisor.

As a result of these two forces justifying an output reduction in state $(\sigma_{i(t+\tau)} = \emptyset, \beta_{i(t+\tau)} = \underline{\beta})$, everything happens as if the true demand faced by the monopolist had been replaced by a lower *virtual demand* $\underline{\beta}(\tau)$.[19] This virtual demand decreases when $k(\cdot)$ gets larger. Intuitively, asymmetric information plays the role of a tax on the firm's output reducing therefore its scale of activity. When the technology of collusion evolves over time, this tax is time-dependent. Note that $\beta(\cdot)$ decreases as $k(\cdot)$ increases.

3.2 Bureaucratization

Students of bureaucracy have soon recognized that large organizations are subject to a rapid decay in their internal efficiency.[20] The underlying idea is that time permits the the development of trust and reciprocity which facilitates the emergence of informal links improving collusion. Transaction costs of side-contracting are thus decreasing over time and $k(\tau)$ is now an arbitrary *increasing* function of the age of the firm.

3.3 Impact of the Dynamics of Transaction Costs on the Growth Rate

We now bring back this pattern of bureaucratization into the framework of Schumpeterian growth. We consider *a stationary equilibrium path* with a constant growth rate and we denote by n^* the size of the skilled labor force used in each R& D sector along this balanced growth path.

Because of the stationarity of our model, any given monopolistic firm i has the same probability of survival in any given period, namely $1-\phi(n^*)$. Using (21), the intertemporal

[19] Myerson (1979) coined this term in a context without collusion.

[20] Downs (1965) has even stated this as a celebrated *Law of Increasing Conservatism "All organisations tend to become more conservative as they get older unless they experience periods of very rapid growth or internal turnover."* Even if Downs' main concern is the behavior of public bureaucracy, his insight should obviously also applies to the private sector.

profit from being a monopolist from date $t+1$ on writes as:

$$\Pi_{i(t+1)} = \sum_{\tau=0}^{\infty} \left(\frac{1-\phi(n^*)}{1+r}\right)^{\tau} \left(\frac{w_{t+\tau+1}}{\alpha^2 \bar{\beta} A_{i(t+1)}}\right)^{\frac{1}{\alpha-1}} w_{t+\tau+1} \left(\nu + (1-\nu)\left(\frac{\beta(\tau)}{\bar{\beta}}\right)^{\frac{1}{1-\alpha}}\right).$$

Let define the wage-productivity adjusted parameter as:

$$\omega_{t+\tau+1} = \frac{w_{t+\tau+1}}{A^{\max}_{t+\tau+1}} = \frac{w_{t+\tau+1}}{A_{i(t+1)}} \times \frac{1}{\prod_{l=0}^{\tau-1}(\phi(n_{t+l})q + 1 - \phi(n_{t+l}))}.$$

Along a balanced growth path, this parameter is a constant denoted by ω^*. Given the symmetry of the model, the monopoly's intertemporal profit is the same in all sectors from any date $t+1$ on and we can denote it by $\Pi_{t+1} = \Pi_{i(t+1)} \quad \forall i \in [0,1]$.

The skilled labor force used in each R& D sector is such that the expected marginal benefit of innovating and being a monopoly from date $t+1$ on equals date t wage given to one more unit of skilled labor. Therefore, n^* is such that:

$$\phi'(n^*)\frac{\Pi_{t+1}}{1+r} = w_t. \tag{22}$$

Simplifying the expression of the intertemporal profit and using (22) yields the following research arbitrage equation

$$\phi'(n^*)\frac{(\phi(n^*)q + 1 - \phi(n^*))}{1+r}\hat{\Pi}\left(\omega^*, n^*, k(\cdot)\right) = \omega^* \tag{23}$$

where $\hat{\Pi}(\omega^*, n^*, k(\cdot))$ is the intertemporal productivity-adjusted profit of a monopolist in any sector. The exact expression of this adjusted profit is:

$$\hat{\Pi}(\omega^*, n^*, k(\cdot)) = \frac{\omega^{*\frac{\alpha}{\alpha-1}}}{(\alpha^2\bar{\beta})^{\frac{1}{\alpha-1}}} \left(\sum_{\tau=0}^{\infty}\left(\frac{(1-\phi(n^*))}{1+r}(\phi(n^*)q + 1 - \phi(n^*))^{\frac{\alpha}{\alpha-1}}\right)^{\tau} \left(\nu + (1-\nu)\left(\frac{\beta(\tau)}{\bar{\beta}}\right)^{\frac{1}{1-\alpha}}\right)\right)$$

To close our general equilibrium model, we write now the skilled labor market clearing equation. First, note that the average output produced by intermediate sectors as a whole in any stationary equilibrium is:

$$\hat{X}(\omega^*, n^*, k(\cdot)) = \sum_{\tau=0}^{\infty} \phi(n^*)(1-\phi(n^*))^{\tau} \tilde{X}_{\tau}(\omega^*, n^*, k(\cdot)).$$

where

$$\tilde{X}_{\tau}(\omega^*, n^*, k(\cdot)) = \left(\frac{\omega^*}{\alpha^2\bar{\beta}}\right)^{\frac{1}{\alpha-1}} (\phi(n^*)q + 1 - \phi(n^*))^{\frac{\tau}{\alpha-1}} \left(\nu + (1-\nu)\left(\frac{\beta(\tau)}{\bar{\beta}}\right)^{\frac{1}{1-\alpha}}\right)$$

is average output of a firm with age τ when it is adjusted by productivity.

To compute this average output of the intermediate sectors, we use the fact that there exists a continuum of those sectors. In a stationary equilibrium, we can thus identify the intertemporal distribution of productivity-adjusted outputs of a given firm with the distribution of those ouputs across sectors. The probability $\phi(n^*)(1-\phi(n^*))^\tau$ is thus simultaneously the number of sectors which are τ steps behind the leading-edge technology and the probability that a firm in a given sector reaches age τ.

Skilled labor is either used in the R& D sectors or to produce intermediate goods. The *skilled labor market clearing condition* in a stationary equilibrium writes thus as:

$$L - n^* = \hat{X}(\omega^*, n^*, k(\cdot)). \tag{24}$$

3.4 Stationary Growth Rate

Along a balanced growth path, the average growth rate of the economy is:

$$g^* = \frac{Y_{t+1} - Y_t}{Y_t}$$

where $Y_t = w_t \hat{X}(\omega^*, n^*, k(\cdot))$ is average GDP of the stationary economy at date t.

On such a path, wages and GDP grow at the same rate as the leading-edge technology. We have

$$\frac{w_{t+1}}{w_t} = \frac{Y_{t+1}}{Y_t} = \phi(n^*)q + 1 - \phi(n^*)$$

and thus:

$$g^* = \phi(n^*)(q-1).$$

Hence, there is a one-to-one positive relationship between the probability of an innovation and the growth rate. Slightly abusing language, we will identify n^* with this growth rate.

3.5 Time-Independent Transaction Costs

As a benchmark, it is interesting to consider the special case where transaction costs are time-independent. Agency costs due to collusive behavior are then also constant over time. We denote by $k(\cdot) = k$ the corresponding efficiency of side-contracting and we observe that the virtual demand parameter $\underline{\beta}(\tau) = \underline{\tilde{\beta}}$ is thus also constant over time.

Let denote by n^0 and ω^0 the stationary growth rate and the productivity adjusted wage when agency costs are constant over time. (23) becomes then:

$$\phi'(n^0)\frac{(\phi(n^0)q + 1 - \phi(n^0))}{1+r}\hat{\Pi}\left(\omega^0, n^0, k\right) = \omega^0 \tag{25}$$

Similarly, (24) writes as:

$$L - n^0 = \hat{X}(\omega^0, n^0, k). \tag{26}$$

Eliminating ω^0 between those two equations, we can determine the stationary equilibrium growth rate as the solution of an equation of the form

$$H(n^0) = 1. \tag{27}$$

where

$$H(n) = \frac{\phi'(n)}{\phi(n)}(L-n)\left(\frac{(\phi(n)q+1-\phi(n)) - (1-\phi(n)(\phi(n)q+1-\phi(n))^{-\frac{\alpha}{1-\alpha}}}{1+r-(1-\phi(n))(\phi(n)q+1-\phi(n))^{-\frac{\alpha}{1-\alpha}}}\right). \tag{28}$$

The following proposition characterizes the shape of $H(\cdot)$ and the equilibrium growth rate n^0:

Proposition 2 *: $H(n)$ is a strictly decreasing function of n.*

- *There always exists a unique stationary equilibrium growth rate n^0 which does not depend on k the time-independent efficiency of side-contracting.*
- *n^0 is equal to the complete information growth rate.*

• (23) and (24) can easily be drawn in the (n^*, ω^*) space. Under the assumptions made on the R&D technology, (23) always defines a downward sloping curve. Instead, (24) is upward sloping (see Figure 1). These two properties ensure that $H(\cdot)$ is strictly increasing and guarantees thereby the uniqueness of the equilibrium growth rate when transaction costs are constant over time.

• In the standard Schumpeterian model à la Aghion and Howitt (1998), the equilibrium growth rate does not depend on the size of demand. Demand only enters into the expression of this growth rate through its price elasticity.[21] Similarly here, the growth rate is unaffected by changes in the quality of the matches between the intermediate goods and the final sectors since this quality only affects demand multiplicatively and, therefore, does not perturb the elasticity of demand. Remember that agency costs within intermediate sectors replace indeed qualities by virtual qualities. Hence, agency costs play the same role as a tax on the price for intermediate goods. Agency costs affect only the scale of activity but leave unchanged the demand elasticity. Therefore, when they are exogenous and constant over time, transaction costs do not affect equilibrium growth. In particular, the growth rate is the same as under complete information.

[21] See equation (2.3) page 58 in Aghion and Howitt (1998) for instance. This equation differs from (27) because of our choice of working in a discrete time model which is necessary to incorporate the repeated game analysis of Section 5.

4 The Dynamics of Transaction Costs and Shumpeterian Growth

In a Schumpeterian environment, the rate of technological innovation depends on the profitability of firms which itself depends on the amount of bureaucratization emerging as a response of the threat of internal side-contracting. The internal organization of the firm has also an impact on the aggregate rate of creative destruction and growth in the economy. To stress this causality, we focus now on time-dependent transaction costs of side-contracting which not only affect the scale of activity of the intermediate sectors, but also the intertemporal distribution of profits and outputs across sectors. The growth rate will now depend on the dynamic path of the agency costs incurred to prevent those collusions.

4.1 Two Different Effects of Bureaucratization

• To understand how the bureaucratization of intermediate sectors affects the growth rate of the economy, it is useful to consider the following thought experiment.

Starting from the constant transaction costs benchmark described in Section 3.5, let us consider an upward small shift in the efficiency of internal side-contracting, so that the whole function $k(\cdot)$ becomes now slightly increasing over time. Because such a small shift will not affect uniqueness of the equilibrium growth rate, Figure 1 can still be used to assess the impact of bureaucratization.

With this small shift, the monopoly's profitability goes down since $\hat{\Pi}_k(\cdot) < 0$ and the locus (23) is shifted downwards. This *profitability effect* is the first consequence of the bureaucratization of a monopoly. Slightly abusing language, it is a partial equilibrium effect.

However, when the efficiency of side-contracting increases, intermediate sectors get more bureaucratized and the overall average output of these sectors contracts as a response to the threat of capture. The labor-market clearing equation (24) is also shifted downwards. This is the *reallocation effect* of an increase in the amount of bureaucratization. Bureaucratization in the intermediate sectors rejects more skilled labor into the research sectors. These sectors become therefore more innovative and this increases the rate of creative destruction. This latter effect comes through the general equilibrium aspect of our model.

• As a result of these two forces driven by bureaucratization, the stationary equilibrium growth rate either diminishes when the profitability effect dominates, or instead increases when the reallocation effect dominates. Bureaucratization has then an a priori ambiguous impact on equilibrium growth.

• Using equations (23) and (24) to eliminate ω^*, a stationary equilibrium growth rate is the solution to the equation:

$$H(n^*) = G(n^*), \tag{29}$$

where

$$G(n) = \frac{\psi(\delta)}{\psi\left(\frac{(\phi(n)q+1-\phi(n))}{1+r}\delta\right)} \tag{30}$$

with

$$\psi(\delta) = (1-\delta)\left(\sum_{\tau=0}^{\infty}\delta^{\tau}\left(\nu + (1-\nu)\left(\frac{\beta(\tau)}{\bar{\beta}}\right)^{\frac{1}{1-\alpha}}\right)\right),$$

and

$$\delta = (1-\phi(n))(\phi(n)q+1-\phi(n))^{-\frac{1}{1-\alpha}}.$$

$\psi(\cdot)$ is a discounted sum of terms of the form $\nu + (1-\nu)\left(\frac{\beta(\tau)}{\bar{\beta}}\right)^{\frac{1}{1-\alpha}}$ which are proportional to the average output produced by a firm of age τ. Hence, it is an index of the bureaucratization of the economy. However, these indexes are computed with different discount factors at the numerator and the denominator of $G(\cdot)$. The term $\frac{\phi(n)q+1-\phi(n)}{1+r}$ suggests that the denominator index $\psi\left(\frac{(\phi(n)q+1-\phi(n))}{1+r}\delta\right)$ captures the effect of the bureaucratization on the average intertemporal productivity-adjusted profit of firms. This first term measures the profitability effect. The numerator index $\psi(\delta)$ captures the effect of the bureaucratization on the average productivity-adjusted output of firms across sectors at a given date. This second term measures the reallocation effect.

For further reference, let us define also $\hat{n}$ as the unique solution to:

$$(q-1)\phi(\hat{n}) = r$$

when it exists, i.e., when $(q-1)\phi(L) > r$.[22] $\hat{n}$ is such that the rate of productivity growth is equal to the interest rate. This number is also such that the numerator and the denominator of $G(\cdot)$ are exactly equal. Indeed, as we have already seen, in the special case of constant transaction costs or in the special case where $n = \hat{n}$, $G(n) = 1$ and bureaucratization has no impact on the growth rate which is the same as under complete information. In this case, the profitability and the reallocation effects just swamp each other.

• The functions $H(n)$ and $G(n)$ have be drawn on Figure 2. We have already seen that, under our assumption on the technology of the R&D sectors, $H(n)$ always defines a downward sloping curve. Instead, depending on the relative importance of the partial and

[22] We will make this assumption from now on. Otherwise, i.e., when $(q-1)\phi(L) < r$, we will be obliged to set $\hat{n} = L$.

general equilibrium effects of bureaucratization, $G(n)$ may be either upward or downward sloping when transaction costs are decreasing. As proved in the Appendix,[23] $G(n)$ is a priori a hump-shaped function of n.[24] This property helps in fact to characterize the stationary equilibrium growth rates of this economy.

4.2 Stationary Equilibrium Growth Rates

We state now our existence result.

Proposition 3 : *When transaction costs of side-contracting are decreasing over time, we have:*

- *If $n^0 < \hat{n}$, there exists a unique stationary equilibrium growth rate n^* such that*

$$n^0 < n^* < \hat{n}.$$

- *If $n^0 > \hat{n}$, there exists at least one stationary equilibrium growth rate n^*. There may nevertheless exist multiple equilibria. In any case, all these equilibria are such that*

$$n^0 > n^* > \hat{n}.$$

- *If $n^0 = \hat{n}$, there exists a unique stationary equilibrium growth rate n^* such that*

$$n^0 = n^* = \hat{n}.$$

• **Growth Rate Distortions**: For a relatively drastic innovation or for a small interest rate (i.e., when $q-1$ is large and when r is small), $\hat{n}$ is small and the denominator of $G(\cdot)$ is greater than its numerator. In this case, the profitability effect of bureaucratization always dominates the reallocation effect.

The firm's productivity-adjusted profitability diminishes over time as collusion develops. This dampens significantly the incentives of the R&D sectors to innovate. These incentives are indeed driven by the whole sequence of per-period profits made over the entire life of a monopoly since the probability of being replaced is small and there is little discounting. In particular, the level of adjusted-profits achieved when the organization is fully bureaucratized play a major role. The contracting path of activities of the intermediate sectors affects relatively more their intertemporal profit than their average output. As a result, the equilibrium growth rate is lower than under complete information.

[23] See Lemma 1.

[24] To simplify exposition, we will represent graphically on Figure 2 the case where it has only one hump. However, our analytical results hold more generally.

When innovations are not so drastic or when the interest rate r is relatively large (i.e., when $q-1$ is small and when r is large), $\hat{n}$ is large and the reverse phenomenon happens. The productivity-adjusted profitability of intermediate sectors is less affected by a declining path of activity than their average productivity-adjusted output. The incentives of the R&D sectors to innovate are only provided by the profits made in the very first periods of the monopoly's life when it is still not too much affected by bureaucratization. The reallocation effect dominates. A larger share of the skilled labor pool becomes available to work in the R&D sectors and the rate of innovation increases, resulting in more creative destruction. The equilibrium growth rate is always smaller than under complete information.

The possibility that the equilibrium growth rate may be either above or below its value under complete information suggests that economies may follow very different paths depending on how drastic innovations are and how important the interest rate is. Some countries may be stuck with very low growth rates and heavily bureaucratized firms. Other countries may exhibit less bureaucratic structures and at the same time face a higher rate of creative destruction. The first (resp. the second) case is more likely when innovations are drastic (resp. small) and the interest rate is small (resp. large).

• **Multiple Equilibria**: In the case of a quite drastic innovation ($q-1$ large enough so that $\hat{n} < n^0$), less innovation in the R&D sectors makes monopolies in the intermediate sectors enjoy a quite easy life. As their expected life time increases, collusive relationships find more opportunities to form and to have enough time to develop and, consequently to affect significantly the allocation of resources in the economy. This, in turn, decreases the profitability of the intermediate sectors and reduces the incentives of the R&D sectors to innovate. There is then less innovations in each research sector. Because of the public good externality embodied in social knowledge, productivity growth is also less important. This effect decreases even further the profitability of the intermediate sectors. Finally, the incentives of the R&D sectors are further reduced and monopolies have an even quieter life. Thanks to this strategic complementarity between the micro and the macro sides of the model, multiple stationary equilibria may therefore arise.

• **Scale Effect**: One major results of Schumpeterian models is that scale effects are present: the growth rate n^0 depends on the size of the labor market L. However, empirically, this last dependency has received little support.[25] It is easy to see, that, as L increases, $H(\cdot)$ is shifted upwards and thus, the complete information growth rate n^0 also increases but, at the same time, $\hat{n}$ remains constant. In the case of a small increment on innovations, the unique equilibrium growth rate n^* is also shifted upwards as long as

[25] See Jones (1995).

n^0 remains below $\hat{n}$. If L further increases, one may switch regime and n^0 may become greater than $\hat{n}$. Multiple equilibria may then appear with all those equilibria being below n^0. Introducing asymmetric information suggests therefore that large scale changes (such as those arising for instance when international labor markets are integrated) may not be translated in large increases in growth rates. Equilibrium growth rates can remain rather close to $\hat{n}$.

5 Endogenous Transaction Costs

To go further and, in particular, to clarify the relationship between the macroeconomic growth rate and the internal organizational structure of the firm, we now *endogenize* the transaction costs of side-contracting. The equilibrium growth rate will now depend on organizational parameters characterizing the internal structure of a given firm. This provides an interesting link between the organization of firms, their expected life and the rate of creative destruction in the economy.

5.1 Monopolies Life Cycle

The key to generate endogenous transaction costs is to let time plays a crucial role in the formation of coalitions within monopolies of the intermediate sectors. Following Martimort (1999), we give up the assumption that collusion is enforceable through a binding side-agreements running for the current period. Instead, any collusive agreement must be *self-enforceable*. Both the supervisor and the manager must find profitable to continue to collude if the benefits from doing so are larger than the current gains obtained by any of them if he breaks the cooperative behavior.

• **Self-enforceable Collusion**: Let us consider a monopoly in sector i starting its life at date t. The implicit collusive agreements run as follows. The supervisor and the manager collude from any date $t+\tau$ on if an informative signal $\sigma_{i(t+\tau)} = \bar{\beta}$ has been observed by the supervisor. Such a collusion is an implicit contract stipulating bribes $b_{i(t+\tau')}$ at all future dates $\tau' \geq \tau + 1$. These bribes are paid by the manager to the supervisor when the latter gets an informative signal at any of these dates. In exchange, the supervisor does not report these informative signals when they realize.

This implicit contract is sustained with *trigger strategies.* There is a return to a non-cooperative behavior from any date $t+\tau''$ on ($\tau'' \geq \tau'$) if either the supervisor reports $\hat{\sigma}_{i(t+\tau'')} = \bar{\beta}$ to the owners or if the manager fails to give any bribe at date $t+\tau''-1$. Following such a a non-cooperative behavior, the supervisor reports always any informative signal he may have observed and the manager never bribes the supervisor.[26]

• **Dynamic Collusion-Proofness Constraints**: We now derive sufficient conditions such that colluding from date $t + \tau$ is an equilibrium strategy for both the supervisor and the manager. To simplify notations, we analyze an environment characterized by a stationary growth rate and investigate how collusion can be enforced along such a stationary path of the economy.

If the owners have a complete ability to commit to a path of outputs, transfers and wages, they could break any self-enforceable collusive behavior at a cost as close as wanted to zero by promising a large transfer to the supervisor at a date in the far future if he reports an informative signal and deviates from the collusive agreement. To avoid this unpalatable conclusion, we will assume that the owners cannot commit to the transfers they include in the incentive scheme they propose to the agents. Any collusive equilibrium that could start at a date $t + \tau$ has to prevented by inducing a deviation from this equilibrium at date $t+\tau$ itself. However, to capture the effect of the bureaucratization, we assume that owners can still commit the firm on an intertemporal path of productions.[27]

Let us take the subgame starting at date $t + \tau$ when the supervisor has observed the informative signal $\sigma_{i(t+\tau)} = \bar{\beta}$. The supervisor must prefer hiding this informative signal and continuing to collude from that date on when informative signals will be observed rather than immediately reporting this information to the owners of the firm and then behaving always non-cooperatively in the future. The supervisor's incentive constraint in the repeated game starting at date $t + \tau$ writes thus as:

$$S^*_{i(t+\tau)} + \nu\epsilon \sum_{l=1}^{\infty} \left(\frac{1-\phi(n^*)}{1+r} \right)^l S^*_{i(t+\tau+l)} \leq b_{i(t+\tau)} + \nu\epsilon \sum_{l=1}^{\infty} \left(\frac{1-\phi(n^*)}{1+r} \right)^l b_{i(t+\tau+l)}. \tag{31}$$

Similarly, the manager must prefer giving up a bribe $b_{i(t+\tau)}$ and continuing to bribe from that date on when the supervisor is informed rather than not bribing a lenient supervisor today and then being always denounced in the future. The manager's incentive constraint in the repeated game starting at date $t + \tau$ writes thus as:

$$\bar{U}_{i(t+\tau)} \leq \bar{U}_{i(t+\tau)} - b_{i(t+\tau)} + \nu\epsilon \sum_{l=1}^{\infty} \left(\frac{1-\phi(n^*)}{1+r} \right)^l (\bar{U}_{i(t+\tau)} - b_{i(t+\tau+l)}). \tag{32}$$

A contract is *collusion-proof* when it exhausts all possibilities for self-enforceable collusion between the supervisor and the sales managers from any date $t+\tau$ on. There must be no

[26] In our simple game, these trigger strategies turn out to be also optimal in the sense of Abreu (1986). Indeed, the non-cooperative Nash equilibrium yields their minmax payoffs to both the supervisor and the manager in the (time-dependent) stage game.

[27] One possible justification behind this limited commitment assumption is that those large transfers are not credible and that owners want to revise downwards any large promises they could have done in the past to the agents. See Martimort (1999). A second justification is that this assumption on commitment also provides the path of endogenous transaction costs analyzed in Section 4.

possible stream of bribes such that (31) and (32) simultaneously hold. This leads to the condition:

$$S^*_{i(t+\tau)} + \nu\epsilon \sum_{l=1}^{\infty} \left(\frac{1-\phi(n^*)}{1+r} \right)^l S^*_{i(t+\tau+l)} \geq \nu\epsilon \sum_{l=1}^{\infty} \left(\frac{1-\phi(n^*)}{1+r} \right)^l \bar{U}_{i(t+\tau+l)} \qquad (33)$$

(33) is the *dynamic collusion-proofness constraint* which must be satisfied to prevent agents from starting to collude from date $t+\tau$ on. When owners optimize over the wages they offer to the supervisor to prevent collusion, this constraint must be binding to prevent the collusive behavior starting at date $t+\tau$.

The important thing to note is that, over time, there are more and more of these dynamic collusion-proofness constraints which must be satisfied by the optimal collusion-proof contract. The reason is that a new self-enforceable collusion may start from each date on when $\sigma_{i(t+\tau)} = \bar{\beta}$. Moreover, the information rent at date $t+\tau+1$, $\bar{U}_{i(t+\tau+1)}$, enters exactly into τ different dynamic collusion-proofness constraints, namely all the constraints preventing the collusive agreements that could have started at all previous dates $t+\tau'$ with $0 \leq \tau' \leq \tau$. Therefore, there are more and more reasons to reduce these information rents as τ gets larger, i.e., as the firm gets holder.

Over the monopoly's life, the manager's information rent is thus decreasing and the supervisor's discretionary power diminishes. Rules become more bureaucratic as the monopoly gets older. The bureaucratization of the firm takes place.

Moreover, optimizing over collusion-proof contracts, we find that the optimal production path can be fully replicated by a model assuming exogenous transaction costs and enforceable side-contracts provided that transaction costs follows the dynamics described below.

Proposition 4 *: When collusion within the monopolistic firm is self-enforceable, average output and average profit at date $t+\tau$ are respectively given by (20) and (21) provided that transaction costs are now defined as $1-k(\tau,\nu\epsilon)$ where*

$$k(\tau,\nu\epsilon) = 1-(1-\nu\epsilon)^{\tau}. \qquad (34)$$

Moreover, per-period profit and average output decrease with the age τ of the monopoly.

Those transaction costs diminish over time to capture the fact that there exists an increasing number of opportunities for a vertical collusion to form. In the limit of $\tau = \infty$, $k(\cdot)$ converges to 1, capturing the fact that supervision is completely useless in old fully bureaucratized monopolies. The assumption made in Section 4 that transaction costs decrease over time is thus given a justification. However, we also learn from the above analysis that these transaction costs depend on the quality of the monitoring technology. The efficiency of side-contracting increases with ϵ. Indeed, better supervisory information increases the continuation value of keeping on colluding since the state of nature in which collusion occurs is more likely.

5.2 Comparative Statics

To derive the complete consequences of this structure of transaction costs on the equilibrium growth rate, we now assume that the spread of uncertainty $\Delta\beta$ is small enough.[28] Using simple Taylor expansions, we are going to assess how simple organizational parameters affect the growth rate of the economy. First, we obtain the following approximation of the equilibrium growth rate of the economy:

Proposition 5 *: Assume that $\Delta\beta$ is small enough, then there exists a unique stationary equilibrium growth rate n^* such that (up to terms of order $\Delta\beta^2$):*

$$n^* - n^0 = -\Delta\beta W(n^0, \nu\epsilon, q, r) \tag{35}$$

where $W(\cdot)$ is a function such that $W(n^0, \nu\epsilon, q, r) > 0$ (resp. < 0) whenever $n^0 > \hat{n}$ (resp. $n^0 < \hat{n}$).

Note immediately that $n^* < n^0$ (resp. $n^* > n^0$) when $n^0 > \hat{n}$ (resp. $n^0 < \hat{n}$) as already shown in Proposition 3.

5.2.1 Spread of Uncertainty

An increase in $\Delta\beta$ enlarges the difference between n^* and n^0. Agency costs due to bureaucratization become more important when uncertainty is larger. Large adverse selection problems which are very likely to call for the implementation of more efficient monitoring devices within the firms have thus a significant impact on the equilibrium growth rate. This growth rate can contract or expand depending on the size of the innovation and the interest rate.

5.2.2 Monitoring Structures and Organizational Innovations

As it has been forcefully argued by Chandler (1962), most of organizational reforms which took place within the larger firms over the last century have concerned changes in their monitoring technologies and structures. A more efficient monitoring technology improves

[28] This simplification is made for tractability but we feel confident on the robustness of the insights that we derive thereafter when this spread gets in fact larger.

the probability that the supervisor gets an informative signal on the manager. We now investigate the consequences of such an improvement on the equilibrium growth rate.

Corollary 1 : *A more informative monitoring technology increases the distortion in the equilibrium growth rate;* $|n^* - n^0|$ *is increasing with* ϵ.

The key to understand this corollary is again to come back to the origins of transaction costs of side-contracting. When the supervisor gets more often an informative signal on the manager, the continuation values of their respective payoffs if they keep on colluding increases. Transaction costs of side-contracting diminish as it can be seen on (34). The organizational response to the threat of collusive behavior, i.e., the firm's bureaucratization, must thus be more pronounced. As a result, when the profitability effect dominates, i.e., in economies with drastic innovations or with small interest rates the growth rate is further decreased compared to the case of complete information. In economies with less drastic innovations or larger interest rates, the reverse phenomenon happens: the reallocation effects dominates and the growth rate increases. Summarizing, the equilibrium growth rate may be more distorted away from its complete information value as monitoring information systems improve. This also shows that changes in the internal structure of the firm may have strong macroeconomic consequences.

This last result suggests a number of empirical implications of our model. First, if asymmetric information did not matter in the economy, the growth rate would be n^0 which is independent of ϵ. Hence, organizational innovations should have no impact on the equilibrium growth rate. If any impact is observed, it must be that asymmetric information matters. Moreover, in this case, an increase in the growth rate as organizational innovations are implemented tells us also that $n^0 < \hat{n}$ and the reallocation effect drives the sign of the distortion. Reciprocally, a decrease in the growth rate tells us that $n^0 < \hat{n}$ and the profitability effect drives the sign of the distortion. Hence, our model also predicts that organizational innovations stimulate the growth rate when product innovations are not drastic ($q-1$ small) and slow down growth when product innovations are drastic ($q-1$ large). This points out to a possible substitutability between product and organizational innovations in the growth process.

5.2.3 Norms of Collusive Behavior

So far, we have assumed that collusion occurs whenever possible within the firm. Each time a supervisor observes an informative signal on the manager, he may refuse to reveal this information if he is bribed. It is immediate to extend our framework to the case where, conditionally on having observed this signal, the supervisor and the manager only collude with some positive probability x. Everything happens as if ϵ is now replaced by $\epsilon' = \epsilon x$ in (34). x can then be viewed as an index of the norm for collusive behavior which establishes in society. Larger values of x correspond to highly corrupted behavior internal to the firm.

Corollary 2 *: A more collusive norm increases the distortion in the equilibrium growth rate; $|n^* - n^0|$ is increasing with x.*

When the norm of collusive behavior is stronger, the manager's and the supervisor's continuation values of keeping on colluding increase. Transaction costs of side-contracting diminish and the organizational response, i.e., the firm's bureaucratization, must be more pronounced. As a result, when the partial equilibrium (resp. general equilibrium) effect dominates, the growth rate is further decreased (resp. increased) compared to the complete information growth rate.

6 Conclusion

In the above model, the macroeconomic environment and the microeconomic conditions strongly interact to determine the equilibrium growth rate. A lower (resp. higher) rate of creative destruction increases (resp. decreases) the expected life of agents within organizations. It therefore increases (resp. decreases) their ability to collude efficiently and to undermine the firm's average profitability. This, in turn, reduces (resp. increases) the incentives of the R&D sectors to innovate. The growth rate of the economy is thus shown to be highly dependent on the dynamics of transaction costs of side-contracting taking place within the firm. Social relationships on the work place have a truly important macroeconomic impact through this channel.

One important point of our analysis should be stressed. Indeed, in our model, whether the dynamics of transaction costs within the firm is exogenously given (Section 4) or whether this dynamics is endogenously derived (Section 5), it remains in both cases independent on the macroeconomic environment. One could add, in an ad hoc fashion, this interesting feedback by making the efficiency of side-contracting be dependent on some social investment which affects the reallocation effect.[29] Of course, ideally the incentives of building social relationships within the firms should be derived from more primitive concerns, like the fear of management of being replaced either within the incumbent firm or by outsiders as a new innovation appears. More generally, other important effects can appear when innovations are adopted within incumbents firm. The implementation of

[29] See Martimort and Verdier (2000) for a static model along these lines.

innovations can be delayed in models à la Aghion, Dewatripont and Rey (1999) when collusion between managers and supervisors allows the latter to share the rents associated to the old technology.[30] This leads to some inertia reducing the profitability and the reallocation effects.

In our model, the life cycle of the firm is always on the contracting side. Allowing for a phase of expansion of the firm could be done at a minimal cost by introducing learning by doing (marginal costs β being a decreasing function of past productions) or informational learning (ϵ being an increasing function of time). The profitability and the reallocation effects would be, again, both affected by the intertemporal distribution of profits and production in ways which may incorporate much of the insights discussed above.

Our results have been derived in a simple stationary equilibrium. However, as it has been shown by Olson (1982), the sclerosis phenomena faced by societies subject to the formation of collusions may be better analyzed as a non-stationary phenomenon. Even if moving to a non-stationary environment certainly involves lots of technical difficulties, this extension may be interesting to develop to understand how organizational forms affect convergence towards a given stationary equilibrium growth rate. One possible way to generate these non-stationarities would be to analyze a one-sector version of our model, or equivalently, a model of growth with a General Purpose Technology.[31] Indeed, with a single sector, the decreasing path of activity within the sector implies that necessarily the incentives of the research sector can no longer be time invariant.

Our model has stressed a particular kind of dynamic agency costs: those implied by time-dependent collusion. Of course, other agency models may generate other roles for time and history. In particular, even when history dependent contracts are optimal,[32] they generate also a stream of time-dependent profits for the firm. The intertemporal distribution of profits and the average across sector outputs are likely to play similar, albeit potentially opposite, roles as those of the present paper. Again, the equilibrium growth rate will balance the impact of the time-distribution of activity on both the profitability and the reallocation effects.

We leave these extensions of our theory for further research.

[30] This is reminiscent of papers in the political economy of technological change which analyze vested interests as a source of stagflation (Krussel and Rios-Rull (1996) and Jovanovic and Nyarko (1994)). In those models, decision-making is made through voting for or against a new technology. There exists a bias for stagflation when old agents benefiting from a learning effect have the control of the political process.

[31] See Helpman and Trajtenberg (1998) for instance.

[32] See Townsend (1982) among many others.

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Figure 1: Partial and General Equilibrium Effects

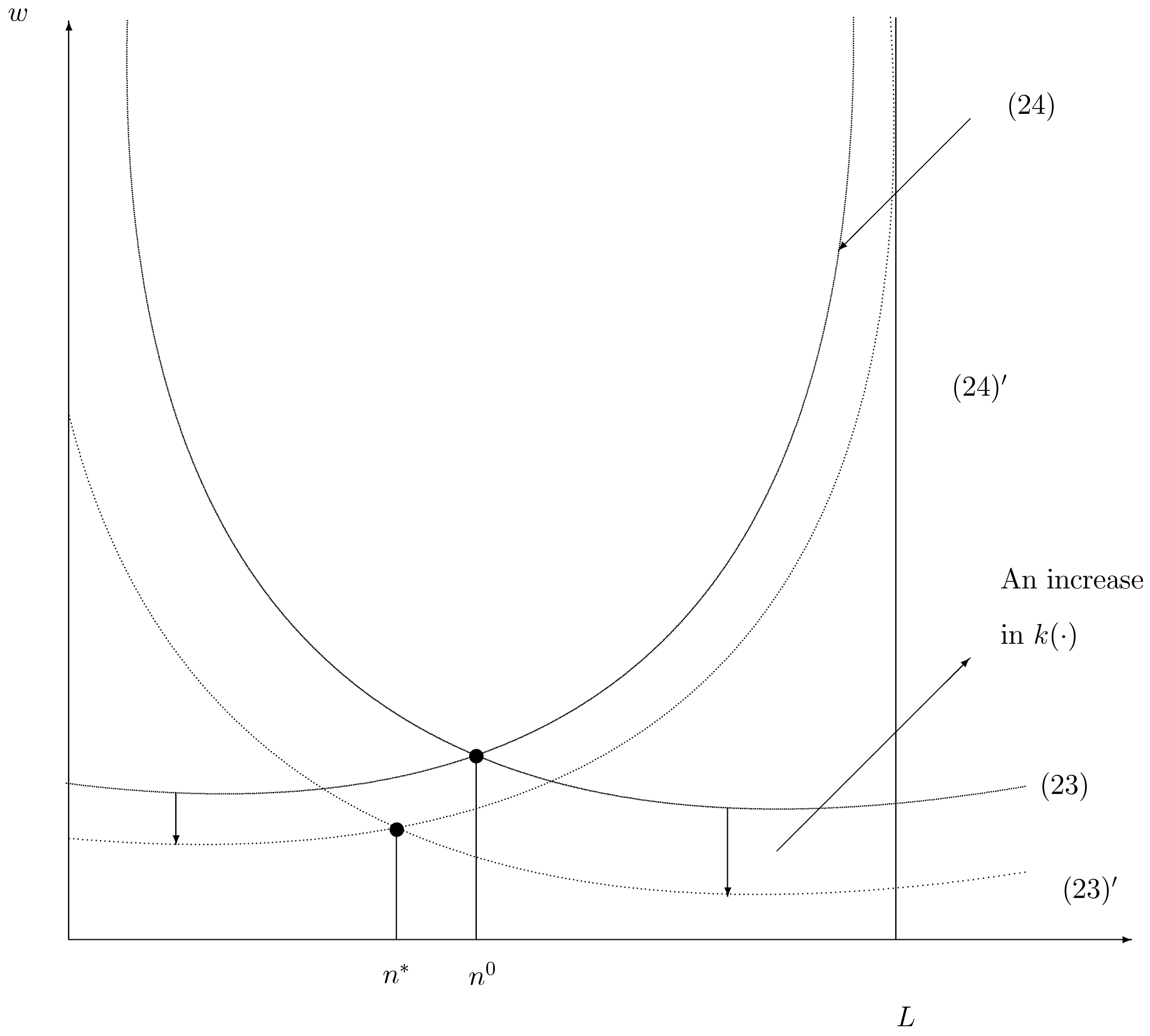
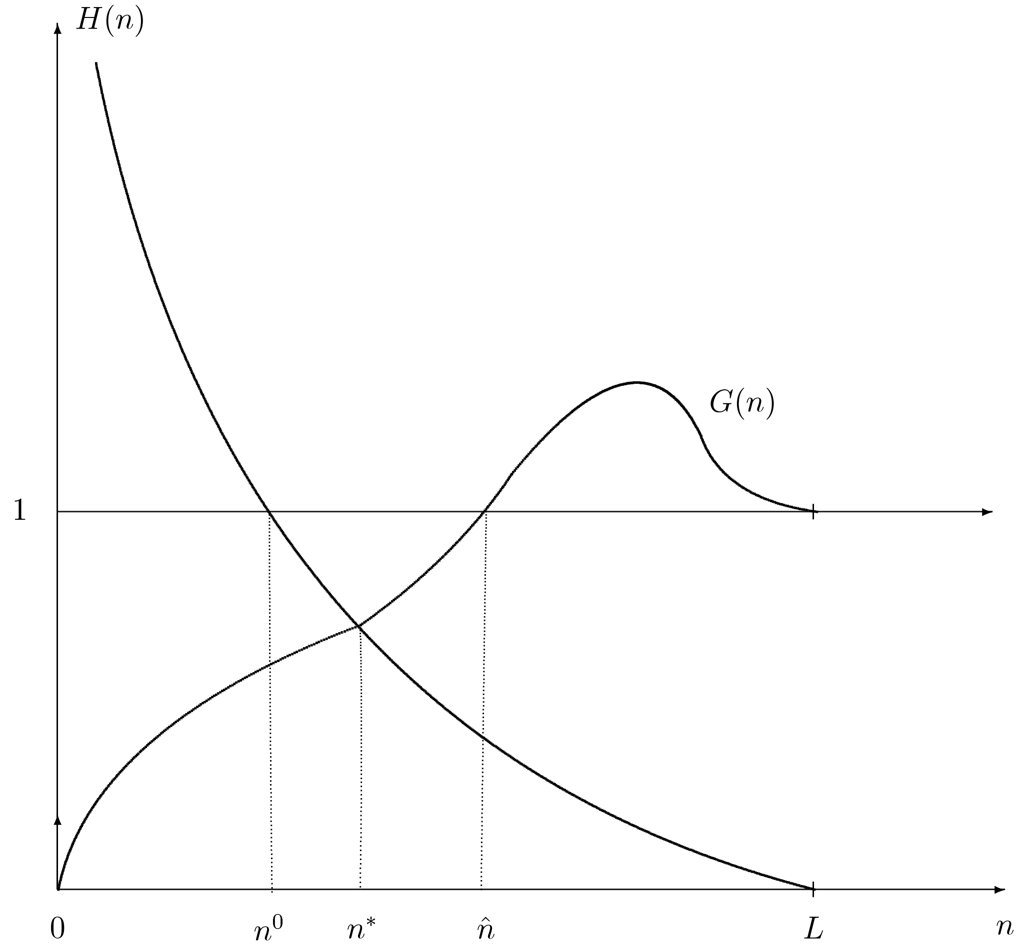
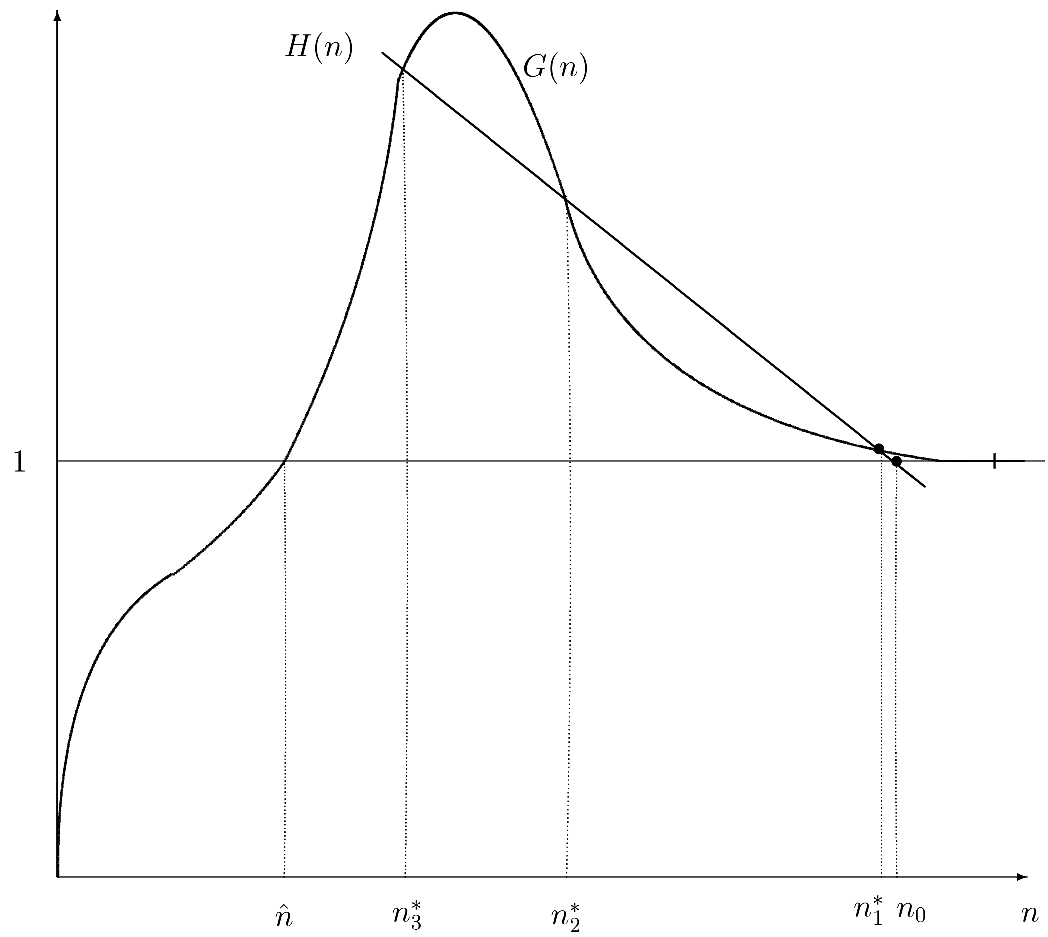


Figure 2: Equilibrium Growth Rates



Case $\hat{n} > n_0$



Case $\hat{n} < n_0$

Appendix

Proof of Proposition 1:

It is standard to show that all constraints (8) to (**??**) are in fact binding at the optimum. Inserting the corresponding values of $\bar{U}^*_{i(t+\tau)} = 0$, $\bar{U}_{i(t+\tau)} = \alpha A_{it}\Delta\beta \underline{x}^{\alpha}_{i(t+\tau)}$, $\underline{U}_{i(t+\tau)} = 0$, $\underline{S}_{i(t+\tau)} = 0$, $\bar{S}_{i(t+\tau)} = 0$, $\underline{S}^*_{i(t+\tau)} = k(\tau)\alpha A_{it}\Delta\beta \underline{x}^{\alpha}_{i(t+\tau)}$ into the owners' objective function and optimizing with respect to $\bar{x}_{i(t+\tau)}, \underline{x}_{i(t+\tau)}$ and $\bar{x}^*_{i(t+\tau)}$, we obtain (17) and (18).

Explicit expressions of $\hat{\Pi}(\omega^*, n^*, k(\cdot))$, $\tilde{X}_\tau(\omega^*, n^*, k(\cdot))$ **and** $\hat{X}(\omega^*, n^*, k(\cdot))$: The intertemporal profit from being a monopolist from date $t+1$ on writes as:

$$\Pi_{i(t+1)} = \sum_{\tau=0}^{\infty} \left(\frac{1-\phi(n^*)}{1+r}\right)^{\tau} \left(\frac{w_{t+\tau+1}}{\alpha^2 \overline{\beta} A_{i(t+1)}}\right)^{\frac{1}{\alpha-1}} w_{t+\tau+1} \left(\nu + (1-\nu)\left(\frac{\underline{\beta}(\tau)}{\overline{\beta}}\right)^{\frac{1}{1-\alpha}}\right).$$

Given the symmetry of the model, the monopoly's intertemporal profit is the same in all sectors from any date $t+1$ on and we can denote $\Pi_{t+1} = \Pi_{i(t+1)} \quad \forall i \in [0,1]$. Hence, we obtain the intertemporal productivity-adjusted profit of a monopolist in any sector as:

$$\hat{\Pi}(\omega^*, n^*, k(\cdot)) = \Pi_{t+1}/A^{\max}_{t+1}$$

given by:

$$\hat{\Pi}(\omega^*, n^*, k(\cdot))$$

$$= \left(\sum_{\tau=0}^{\infty}\left(\frac{(1-\phi(n^*))}{1+r}(\phi(n^*)q + 1 - \phi(n^*))^{\frac{\alpha}{\alpha-1}}\right)^{\tau} \left(\nu + (1-\nu)\left(\frac{\underline{\beta}(\tau)}{\overline{\beta}}\right)^{\frac{1}{1-\alpha}}\right)\right) \frac{\omega^{*\frac{\alpha}{\alpha-1}}}{(\alpha^2\overline{\beta})^{\frac{1}{\alpha-1}}}$$

We write then the skilled labor market clearing equation. First the average output produced by the intermediate sector in a stationary equilibrium is:

$$\sum_{\tau=0}^{\infty} \phi(n^*)(1-\phi(n^*))^{\tau} \tilde{X}_\tau.$$

where:

$$\tilde{X}_\tau(\omega^*, n^*, k(\cdot)) = \left(\frac{\omega^*}{\alpha^2\overline{\beta}}\right)^{\frac{1}{\alpha-1}} (\phi(n^*)q + 1 - \phi(n^*))^{\frac{\tau}{\alpha-1}} \left(\nu + (1-\nu)\left(\frac{\underline{\beta}(\tau)}{\overline{\beta}}\right)^{\frac{1}{1-\alpha}}\right). \quad (36)$$

Note that skilled labor is either used in the R&D sectors or to produce intermediate goods. The *skilled labor market clearing condition* in a stationary equilibrium writes thus as:

$$L = n^* + \hat{X}(\omega^*, n^*, k(\cdot)) \quad (37)$$

where $\hat{X}(\omega^*, n^*, k(\cdot)) = \sum_{\tau=0}^{\infty} \phi(n^*)(1-\phi(n^*))^{\tau} \tilde{X}_\tau(\omega^*, n^*, k(\cdot))$ is average output:

$$\hat{X}(\omega^*, n^*, k(\cdot)) = \left(\sum_{\tau=0}^{\infty}\left((1-\phi(n^*))(\phi(n^*)q + 1 - \phi(n^*))^{\frac{1}{\alpha-1}}\right)^{\tau} \left(\nu + (1-\nu)\left(\frac{\underline{\beta}(\tau)}{\overline{\beta}}\right)^{\frac{1}{1-\alpha}}\right)\right) \left(\frac{\omega^*}{\alpha^2\overline{\beta}}\right)^{\frac{1}{\alpha-1}}$$

Substitution provides an explicit labor market clearing condition as:

$$L = n^* + \left(\frac{\omega^*}{\alpha^2 \overline{\beta}}\right)^{\frac{1}{\alpha-1}} \left(\sum_{\tau=0}^{\infty} \phi(n^*) \left((1-\phi(n^*))(\phi(n^*)q + 1 - \phi(n^*))^{\frac{1}{\alpha-1}}\right)^{\tau} \left(\nu + (1-\nu)\left(\frac{\underline{\beta}(\tau)}{\overline{\beta}}\right)^{\frac{1}{1-\alpha}}\right)\right)$$

Explicit expression of the function $H(\cdot)$: Using the explicit expression of $\hat{\Pi}(\omega^0, n^0, k(\cdot))$, with constant transaction costs $k(\cdot) = k$, (23) becomes:

$$\phi'(n^0)\frac{(\phi(n^0)q + 1 - \phi(n^0))}{1+r}\left(\nu + (1-\nu)\left(\frac{\tilde{\underline{\beta}}}{\overline{\overline{\beta}}}\right)^{\frac{1}{1-\alpha}}\right)\frac{1}{\left(1 - \left(\frac{1-\phi(n^0)}{1+r}\right)(\phi(n^0)q + 1 - \phi(n^0))^{\frac{\alpha}{\alpha-1}}\right)} \tag{38}$$

$$= \left(\frac{\omega^0}{\alpha^2 \overline{\beta}}\right)^{\frac{1}{1-\alpha}}.$$

with

$$\tilde{\underline{\beta}} = \underline{\beta} - \frac{\nu}{1-\nu}\Delta\beta\,(1 - \epsilon + \epsilon k) < \underline{\beta}. \tag{39}$$

Similarly, using the explicit expression of $\hat{X}(\omega^0, n^0, k(\cdot))$, (24) writes as:

$$L - n^0 = \frac{\phi(n^0)}{\left(1 - (1-\phi(n^0))(\phi(n^0)q + 1 - \phi(n^0))^{\frac{1}{\alpha-1}}\right)}\left(\nu + (1-\nu)\left(\frac{\tilde{\underline{\beta}}}{\overline{\overline{\beta}}}\right)^{\frac{1}{1-\alpha}}\right)\left(\frac{\omega^0}{\alpha^2\overline{\beta}}\right)^{\frac{1}{\alpha-1}}, \tag{40}$$

where n^0 and ω^0 are respectively the stationary growth rate and the productivity adjusted wage when agency costs are constant over time.

Using (38) and (40) to eliminate ω^0, the stationary equilibrium growth rate solves the following equation:

$$H(n^0) = \frac{\phi'(n^0)}{\phi(n_0)}(L - n^0)\left(\frac{(\phi(n^0)q + 1 - \phi(n^0)) - (1 - \phi(n^0)(\phi(n^0)q + 1 - \phi(n^0))^{-\frac{\alpha}{1-\alpha}}}{1 + r - (1-\phi(n^0))(\phi(n^0)q + 1 - \phi(n^0))^{-\frac{\alpha}{1-\alpha}}}\right) = 1 \tag{41}$$

Proof of Proposition 2:

• (38) defines a downward sloping curve. Note that (38) rewrites as:

$$\frac{1}{\left(\nu + (1-\nu)\left(\frac{\underline{\beta}(\tau)}{\overline{\beta}}\right)^{\frac{1}{1-\alpha}}\right)}\left(\frac{\omega^0}{\alpha^2\overline{\beta}}\right)^{\frac{1}{1-\alpha}}$$

$$= \frac{(\phi(n^0)q + 1 - \phi(n^0))}{1+r}\frac{\phi'(n^0)}{\left(1 - \frac{(1-\phi(n^0))}{1+r}(\phi(n^0)q + 1 - \phi(n^0))^{\frac{\alpha}{\alpha-1}}\right)}. \tag{42}$$

We observe that

$$\frac{d}{dn}\left((\phi(n)q+1-\phi(n))\phi'(n)\right)=\phi''(n)+(q-1)(\phi''(n)\phi(n)+\phi'(n)^2)<0$$

under the assumption $\phi''(n)\phi(n)+\phi'(n)^2<0$ for all n. Similarly, we have

$$\frac{d}{dn}\left(1-\frac{(1-\phi(n))}{1+r}(\phi(n)q+1-\phi(n))^{\frac{\alpha}{\alpha-1}}\right)=$$

$$\frac{\phi'(n)(\phi(n)q+1-\phi(n))^{\frac{\alpha}{\alpha-1}-1}}{1+r}\left(\phi(n)q+1-\phi(n)+\frac{\alpha}{1-\alpha}(q-1)(1-\phi(n))\right)>0$$

since $q>1$ and $\alpha<1$. Hence, the right-hand-side of (42) is decreasing with n^0 and (38) defines a downward sloping curve.

• (40) defines an upward sloping curve. Note that (40) rewrites as:

$$\left(\nu+(1-\nu)\left(\frac{\beta(\tau)}{\overline{\beta}}\right)^{\frac{1}{1-\alpha}}\right)\left(\frac{\omega^0}{\alpha^2\overline{\beta}}\right)^{\frac{1}{\alpha-1}}=\frac{(L-n^0)\left(1-(1-\phi(n^0))(\phi(n^0)q+1-\phi(n^0))^{\frac{1}{\alpha-1}}\right)}{\phi(n^0)}. \tag{43}$$

We observe that

$$\frac{d}{dn}(L-n)<0.$$

Similarly,

$$\frac{d}{dn}\left(\frac{(1-(1-\phi(n))(\phi(n)q+1-\phi(n))^{\frac{1}{\alpha-1}})}{\phi(n)}\right)=$$

$$\frac{\phi'(n)}{\phi^2(n)}\left(-1+(\phi(n)q+1-\phi(n))^{\frac{1}{\alpha-1}-1}\left(\phi(n)q+1-\phi(n)+\frac{\phi(n)(1-\phi(n))(q-1)}{(1-\alpha)}\right)\right).$$

This function is decreasing when

$$(\phi(n)q+1-\phi(n))^{\frac{1}{1-\alpha}}>1+\frac{\phi(n)(1-\phi(n))(q-1)}{(1-\alpha)(\phi(n)q+1-\phi(n))}.$$

The right-hand-side above can be bounded below by

$$1+\frac{(1-\phi(n))(q-1)}{(1-\alpha)(\phi(n)q+1-\phi(n))}$$

since $\phi(n)\leq 1$. Setting $z=\phi(n)(q-1)$

$$(\phi(n)q+1-\phi(n))^{\frac{1}{1-\alpha}}>1+\frac{(1-\phi(n))(q-1)}{(1-\alpha)(\phi(n)q+1-\phi(n))}$$

holds when $f(z)=(1+z)^{\frac{1}{1-\alpha}}-1-\frac{z}{(1-\alpha)(1+z)}>0$ when $z>0$. Note that $f(0)=0$ and that $f'(z)=\frac{1}{1-\alpha}\left((1+z)^{\frac{1}{1-\alpha}+1}-1\right)>0$ for $z>0$. Hence, $f(z)>0$ for $z>0$.

We deduce from that that the right-hand-side of (43) is decreasing with n^0 and (40) defines therefore an upward sloping curve.

Note that $H(L) = 0$ and $\lim_{n\to 0} H(n) = +\infty$. Hence, if $H(n)$ is strictly decreasing there always exists a unique solution to $H(n) = 1$. However, the condition $\phi''(n)\phi(n) + \phi'(n)^2 \leq 0\ \forall n$, shows that $H(n)$ is in fact decreasing

Properties of $G(n)$: The next Lemma characterizes the behavior of $G(n)$.

Lemma 1 *: $G(n)$ has the following behavior:*

- *$G(n)$ is increasing on an interval $[0, \tilde{n}_1]$ where $L > \tilde{n}_1 > \hat{n}$.*
- *$G(n)$ is decreasing on an interval $[\tilde{n}_2, L]$ where $L > \tilde{n}_2 > \tilde{n}_1$.*
- *$G(n)$ is strictly lower than 1 on the interval $[0, \hat{n}[$ with $G(0) < 1$ and $G(\hat{n}) = 1$.*
- *$G(n)$ is strictly greater than 1 on the interval $]\hat{n}, L[$ with $G(L) = 1$.*

• To prove this define first: $\psi(x) = (1-x)\left(\sum_{\tau=0}^{\infty} x^{\tau}\tilde{H}(\tau)\right)$ with $\tilde{H}(\tau) = \nu + (1-\nu)\left(\frac{\underline{\beta}(\tau)}{\overline{\beta}}\right)^{\frac{1}{1-\alpha}}$. We observe that:

$$\psi'(x) = \sum_{\tau=1}^{\infty} \tau x^{\tau-1}\tilde{H}(\tau) - \sum_{\tau=0}^{\infty}(\tau+1)x^{\tau}\tilde{H}(\tau) = \sum_{\tau=1}^{\infty}\tau x^{\tau-1}\left(\tilde{H}(\tau) - \tilde{H}(\tau-1)\right).$$

Since $\underline{\beta}(\tau)$ is decreasing with τ, $\tilde{H}(\tau) < \tilde{H}(\tau-1)$ and thus $\psi'(x) < 0$.

• Define now $\tilde{G}(x,\phi) = \dfrac{\psi\left(\frac{x}{\phi q+1-\phi}\right)}{\psi\left(\frac{x}{1+r}\right)}$. Note first that $\tilde{G}((1-\phi(n))(\phi(n)q+1-\phi(n))^{\frac{-\alpha}{1-\alpha}}, \phi(n)) = G(n)$.

We have

$$\frac{\frac{\partial \tilde{G}(x,\phi)}{\partial x}}{\tilde{G}(x,\phi)} = \frac{1}{(\phi q+1-\phi)}\left(\frac{\psi'\left(\frac{x}{\phi q+1-\phi}\right)}{\psi\left(\frac{x}{\phi q+1-\phi}\right)} - \frac{(\phi q+1-\phi)}{1+r}\frac{\psi'\left(\frac{x}{1+r}\right)}{\psi\left(\frac{x}{1+r}\right)}\right).$$

But

$$\frac{\frac{d}{dx}\left(\frac{\psi'(x)}{\psi(x)}\right)}{\left(\frac{\psi'(x)}{\psi(x)}\right)} = \frac{\sum_{\tau=0}^{\infty}(\tau+1)(\tau+2)x^{\tau}\left(\tilde{H}(\tau+2) - \tilde{H}(\tau+1)\right)}{\sum_{\tau=0}^{\infty}(\tau+1)x^{\tau}\left(\tilde{H}(\tau+1) - \tilde{H}(\tau)\right)} - \frac{\psi'(x)}{\psi(x)}.$$

Since $\tilde{H}(\tau+1) < \tilde{H}(\tau)$ and $\psi'(x) < 0$, we have thus

$$\frac{d}{dx}\left(\frac{\psi'(x)}{\psi(x)}\right) < 0.$$

Hence, for $\phi(q-1) > r$

$$0 > \frac{\psi'\left(\frac{x}{\phi q+1-\phi}\right)}{\psi\left(\frac{x}{\phi q+1-\phi}\right)} > \frac{\psi'\left(\frac{x}{1+r}\right)}{\psi\left(\frac{x}{1+r}\right)} > \frac{(\phi q+1-\phi)}{1+r}\frac{\psi'\left(\frac{x}{1+r}\right)}{\psi\left(\frac{x}{1+r}\right)},$$

and thus $\frac{\partial \tilde{G}(x,\phi)}{\partial x} > 0$.

Similarly, for $\phi(q-1) < r$

$$0 > \frac{(\phi q+1-\phi)}{1+r}\frac{\psi'\left(\frac{x}{1+r}\right)}{\psi\left(\frac{x}{1+r}\right)} > \frac{\psi'\left(\frac{x}{1+r}\right)}{\psi\left(\frac{x}{1+r}\right)} > \frac{\psi'\left(\frac{x}{\phi q+1-\phi}\right)}{\psi\left(\frac{x}{\phi q+1-\phi}\right)},$$

and $\frac{\partial \tilde{G}(x,\phi)}{\partial x} < 0$.

• We have also:

$$\frac{\partial \tilde{G}(x,\phi)}{\partial \phi} = -\frac{x(q-1)}{(\phi q+1-\phi)^2}\frac{\psi'\left(\frac{x}{\phi q+1-\phi}\right)}{\psi\left(\frac{x}{1+r}\right)} > 0$$

since $\psi'(\cdot) < 0$.

• We denote $x(n) = (1-\phi(n))(\phi(n)q+1-\phi(n))^{\frac{-\alpha}{1-\alpha}}$, and we observe that:

$$x'(n) = -\phi'(n))(\phi(n)q+1-\phi(n))^{\frac{-\alpha}{1-\alpha}-1}\left(\phi(n)q+1-\phi(n)+\frac{\alpha}{1-\alpha}(1-\phi(n))(q-1)\right) < 0.$$

We can thus write:

$$G'(n) = \frac{\partial \tilde{G}(x(n),\phi(n))}{\partial x}x'(n) + \frac{\partial \tilde{G}(x(n),\phi(n))}{\partial \phi}\phi'(n).$$

Assume first that $n \leq \hat{n}$, so that $\phi(n)(q-1) \leq r$. Then both $\frac{\partial \tilde{G}(x(n),\phi(n))}{\partial x}x'(n)$ and $\frac{\partial \tilde{G}(x(n),\phi(n))}{\partial \phi}\phi'(n)$ are positive and $G(\cdot)$ is increasing on $[0,\hat{n}]$.

Since $\frac{\partial \tilde{G}(x(n),\phi(n))}{\partial x}x'(n) = 0$ for $n = \hat{n}$ and $\frac{\partial \tilde{G}(x(n),\phi(n))}{\partial \phi}\phi'(n) > 0$ at this point, $G(\cdot)$ is also increasing on $[\hat{n},\tilde{n}_1]$ for some $\tilde{n}_1 > \hat{n}$.

Assume now that $n > \hat{n}$, so that $\phi(n)(q-1) > r$. Then $\frac{\partial \tilde{G}(x(n),\phi(n))}{\partial x}x'(n) \leq 0$ and $\frac{\partial \tilde{G}(x(n),\phi(n))}{\partial \phi}\phi'(n) \geq 0$.

Since $\phi'(L) = 0$ from Inada conditions, $\frac{\partial \tilde{G}(x(n),\phi(n))}{\partial \phi}\phi'(n) = \frac{\partial \tilde{G}(x(n),\phi(n))}{\partial x}x'(n) = 0$ for $n = L$. Hence, $G'(L) = 0$.

Moreover, when $\phi(L) = 1$, $x(L) = 0$ and thus $G(L) = 1$. Similarly, $\phi(0) = 0$, $x(0) = 1$, $\psi(1) = 0$ and thus $G(0) = 0$. Finally, $\frac{x(\hat{n})}{\phi(\hat{n})q+1-\phi(\hat{n})} = \frac{x(\hat{n})}{1+r}$, and thus $G(\hat{n}) = 1$.

• Using that $\psi(\cdot)$ is decreasing,

$$\frac{\psi\left(\frac{x}{\phi q+1-\phi}\right)}{\psi\left(\frac{x}{1+r}\right)} > 1$$

(resp. < 1) when $\phi(q-1) > r$ (resp. $\phi(q-1) < r$) and $G(n) > 1$ (resp. < 1) for $n > \hat{n}$ (resp. $n < \hat{n}$).

• Therefore, $G(\cdot)$ is necessarily decreasing on $[\tilde{n}_2, L]$ for some $\tilde{n}_2 > \tilde{n}_1$.

Proof of Proposition 3:

• Assume first that $n^0 \leq \hat{n}$. $H(\cdot)$ is decreasing and $G(\cdot)$ is increasing on $[n^0, \hat{n}]$. $H(n^0) = 1 \geq G(n^0)$ and $H(\hat{n}) < 1 = G(\hat{n})$, hence, there exists a unique solution n^* to $H(n^*) = G(n^*)$ on $]n^0, \hat{n}[$. Moreover, for $n > \hat{n}$, $H(n) < 1 < G(n)$ and n^* is thus unique.

• Assume now that $n^0 > \hat{n}$. $H(\cdot)$ is decreasing and $G(\cdot)$ is hump-shaped (with possibly several humps) on $[\hat{n}, n^0]$. $H(n^0) = 1 < G(n^0)$ and $H(\hat{n}) > 1 = G(\hat{n})$, hence, there exists at least one solution n^* to $H(n) = G(n)$ on $]\hat{n}, n^0[$.

Proof of Proposition 4: The proof is similar to that of Proposition 1 except that the dynamic collusion-proofness constraint (33) replaces (14) in the optimization of the owners' problem. Let denote by $\mu_{t+\tau}$ the multiplier of the collusion-proofness constraint preventing the collusion starting at date $t+\tau$. Because of symmetry, let also omit index i. Since we are interested in a stationary equilibrium $n_{t+\tau} = n^*$ for all t and τ.

• The Lagrangean L of the owners' problem writes as:

$$L = \sum_{\tau=0}^{\infty} \left(\frac{1-\phi(n^*)}{1+r}\right)^{\tau} \Big[\nu(1-\varepsilon)(\alpha A_t \bar{\beta} \bar{x}_{t+\tau} - \omega_{t+\tau}\bar{x}_{t+\tau}) + \nu\varepsilon(\alpha A_t \bar{\beta} \bar{x}^*_{t+\tau} - \omega_{t+\tau}\bar{x}^*_{t+\tau})$$

$$+(1-\nu)(\alpha A_t \underline{\beta} \underline{x}_{t+\tau} - \omega_{t+\tau}\underline{x}_{t+\tau}) - \nu(1-\varepsilon)\bar{U}_{t+\tau} - \nu\varepsilon S^*_{t+\tau}\Big]$$

$$+\mu_k\left(S^*_{t+\tau} + \nu\varepsilon \sum_{\ell=1}^{\infty} \left(\frac{1-\phi(n^*)}{1+r}\right)^{\ell} S^*_{t+\tau+\ell} - \nu\varepsilon \sum_{\ell=1}^{\infty} \left(\frac{1-\phi(n^*)}{1+r}\right)^{\ell} \bar{U}_{t+\tau+\ell}\right), \tag{44}$$

where we have already noted that $\bar{U}^*_{t+\tau} = S^{\phi}_{t+\tau} = \underline{U}_{t+\tau} = 0$ in the expression above.

• Optimizing with respect to $\bar{x}_{t+\tau}$ and $\bar{x}^*_{t+\tau}$ yields

$$\bar{x}_{t+\tau} = \bar{x}^*_{t+\tau} = \left(\frac{\omega_{t+\tau}}{\alpha^2 \bar{\beta} A_t}\right)^{\frac{1}{\alpha-1}}.$$

• Optimizing with respect to $\underline{x}_{t+\tau}$ yields:

$$\underline{x}_{t+\tau} = \left(\frac{\omega_{t+\tau}}{\alpha^2 \underline{\beta}(\tau) A_t}\right)^{\frac{1}{\alpha-1}}$$

where

$$\underline{\beta}(\tau) = \underline{\beta} - \frac{\nu}{1-\nu}\Delta\beta\left(1-\varepsilon+\varepsilon\sum_{\ell=0}^{\tau-1}\mu_\ell\left(\frac{1+r}{1-\phi(n^*)}\right)\right). \tag{45}$$

• Optimizing with respect to $S^*_{t+\tau}$ and taking into account that $S^*_{t+\tau}$ is finite at the optimum

$$\mu_\tau + \nu\varepsilon\sum_{\ell=0}^{\tau-1}\mu_\tau\left(\frac{1-\phi(n^*)}{1+r}\right)^{\tau-\ell} = \nu\varepsilon\left(\frac{1-\phi(n^*)}{1+r}\right)^{\tau}.$$

We denote thereafter $M_\tau = \sum_{\ell=0}^{\tau-1} \mu_\tau \left(\frac{1-\phi(n^*)}{1+r}\right)^{\tau-\ell}$. Taking into account that $M_0 = 0$ ($\mu_0 = 0$) and that M_τ solves the difference equation

$$M_{\tau+1} - (1-\nu\varepsilon)M_\tau = 1-\nu\varepsilon,$$

we find

$$M_\tau = \left(\frac{\nu\varepsilon}{1+r}\right)\left(1-(1-\nu\varepsilon)^\tau\right).$$

Inserting this expression into (45) yields

$$\underline{\beta}(\tau) = \underline{\beta} - \frac{\nu}{1-\nu}\Delta\beta\left(1-\varepsilon+\varepsilon\left(1-(1-\nu\varepsilon)^\tau\right)\right).$$

• Note that M_τ is strictly increasing so that all multipliers are positive except μ_0.

Proof of Proposition 5: When $\Delta\beta$ is small enough, the following Taylor expansions hold:

$$\psi(x) = (1-x)\left(\sum_{\tau=0}^{\infty} x^\tau \left(1 - \frac{\Delta\beta}{\bar{\beta}(1-x)}(1-\nu\varepsilon) - \frac{\nu^2\varepsilon^2\Delta\beta}{\bar{\beta}(1-\alpha)}\left(\frac{1}{\frac{1}{x}-1+\nu\varepsilon}\right)\right)\right).$$

Hence

$$G(n^*) = \frac{\psi\left((1-\phi(n^*))(\phi(n^*)q+1-\phi(n^*))^{-\frac{1}{1-\alpha}}\right)}{\psi\left(\frac{(1-\phi(n^*))}{1+r}(\phi(n^*)q+1-\phi(n^*))^{-\frac{\alpha}{1-\alpha}}\right)}$$

$$= 1 - \frac{\nu^2\varepsilon^2\Delta\beta}{\bar{\beta}(1-\alpha)}\left(\frac{1}{\frac{(\phi(n^*)q+1-\phi(n^*))^{\frac{1}{1-\alpha}}}{1-\phi(n^*)}-1+\nu\varepsilon} - \frac{1}{\frac{(1+r)(\phi(n^*)q+1-\phi(n^*))^{\frac{\alpha}{1-\alpha}}}{1-\phi(n^*)}-1+\nu\varepsilon}\right).$$

Therefore, we get the following approximation up to terms of higher order:

$$H(n^*)-H(n^0) = -\frac{\nu^2\varepsilon^2\Delta\beta}{\bar{\beta}(1-\alpha)}\left(\frac{1}{\frac{(\phi(n^0)q+1-\phi(n^0))^{\frac{1}{1-\alpha}}}{1-\phi(n^0)}-1+\nu\varepsilon} - \frac{1}{\frac{(1+r)(\phi(n^0)q+1-\phi(n^0))^{\frac{\alpha}{1-\alpha}}}{1-\phi(n^0)}-1+\nu\varepsilon}\right). \quad (46)$$

>From this, (35) obtains immediately when:

$$W(n^0,\nu\epsilon,q,r) = \frac{\nu^2\epsilon^2}{\bar{\beta}(1-\alpha)H'(n^0)}\left(\frac{1}{\frac{(\phi(n^0)q+1-\phi(n^0))^{\frac{1}{1-\alpha}}}{1-\phi(n^0)}-1+\nu\epsilon} - \frac{1}{\frac{(1+r)(\phi(n^0)q+1-\phi(n^0))^{\frac{\alpha}{1-\alpha}}}{1-\phi(n^0)}-1+\nu\epsilon}\right).$$

Proofs of Corollaries 2 and 3: It is immediate from (35).