CIRPÉE
Centre interuniversitaire sur le risque, les politiques économiques et l'emploi

Cahier de recherche/Working Paper **03-25**

Incentive Contracts and Total Factor Productivity

Benjamin Bental
Dominique Demougin

Juin/June 2003

Bental: University of Haifa, Haifa, Israel
bbental@econ.haifa.ac.il
Demougin: Umboldt University at Berlin, Berlin, Germany
ddemoug@wiwi.hu-berlin.de

Abstract: This paper focuses on the endogenous determination of effort as a source of productivity growth. The economy is populated by infinitely lived households. Every period, members of each household may choose whether to be self-employed or become employees in a “corporate sector”. Labor relations in the corporate sector are characterized by a double-moral hazard problem. To induce effort, the optimal labor contract stipulates for a bonus. Nevertheless, due to double moral hazard, employees extract some rents. As the economy grows, employees’ rents increase, thereby raising the marginal benefit of monitoring. The ensuing changes in the optimal labor contract induce higher effort along the growth path. The model creates an endogenous association between growth and total factor productivity, and demonstrates that substantial cross-country productivity differences may be ascribed to differences in incentive structures.

Keywords: Incentive contracts, Total factor productivity, Economic growth

JEL Classification: D82, O40

1. Introduction

Understanding the large differences in total factor productivity (hereafter TFP) among countries is a challenge of great importance to the economics profession. The striking fact is that at the aggregate level, TFP is closely correlated with income (see, for example, Jones [1998]). As a matter of fact, the observation that TFP differences are "responsible" for almost the entire differences in income, has motivated Prescott to impress upon the economics profession the "need" for "a theory of total factor productivity" (Prescott [1998]). Here we show that substantial productivity differences may be ascribed to endogenous differences in the power of incentives embodies in labor contracts.

The differences in TFP have been previously associated by some economists with differences in the access to technology (Romer, [1993]). Others have pointed to differences in factor endowments (in particular of skilled workers) as a source of differences in TFP (Mankiw, Romer and Weil [1992]). Acemoglu and Zilibotti [2001] take the impact of the factor endowment a step further. According to their view, economies which are well endowed with skilled workers are also those that develop new technologies. However, these technologies are suited to skilled workers and not to the less-skilled workers found in LDCs, and therefore the free flow of ideas is insufficient to close the TFP gap.

Prescott [1998] argues that TFP differences are not necessarily due to differences in the stock of knowledge. He cites several studies that demonstrate that TFP differences are associated with differences in work practices and organization. Hall and Jones [1999] argue that social obstacles hinder some economies from adopting high-productivity production technologies. They concentrate on "social infrastructure" as an explanatory variable. According to this explanation, countries whose policies are "favorable to productive activities - rather than diversion - produce much more output per worker". Parente and Prescott [1999] argue that poor economies remain poor because monopolists that control factor supply prevent the adoption of superior technologies. Kocherlakota [2001] concentrates on the technology adoption issue formally. In his paper, it is the ability to enforce a social contract that makes the difference. Economies, in which such an enforcement is not possible, do not adopt a superior production technology (which is available at some cost), while economies in which the social contract is enforceable, do.

We too emphasize the role of institutional arrangements in affecting productivity. In our framework, total factor productivity reflects neither the knowledge of how to produce, nor the factor endowment or the composition of the labor force, but solely workers' effort.[1] Due to information constraints, effort has to be induced by appropriate incentives that are incorporated in the labor contracts. The power of such incentives to induce effort depends crucially on the specific nature of the information constraints. Nevertheless, as an economy grows, the incentive structure of the labor contracts changes endogenously, and induces higher effort and productivity.

We develop an example of these processes in a framework that combines a standard growth environment with a principal-agent model characterized by dou-

[1] Schmitz's [2001] very detailed study of labor productivity of the U.S. and Canadian iron-ore industries shows that great productivity gains can be attributed to changes in effort per hour worked and in work rules. Schmitz argues that his case study demonstrates that "productivity differences across other industries may be also due in some substantial part to factors other than production technology, physical capital and human capital."

ble moral hazard.[2] Specifically, we consider an economy in which two technologies may be used to produce the same good. The first technology uses only labor as input and workers are "self employed". However, not all workers are identical in their productivity if they choose to be self employed. The second technology uses capital and labor and is operated by "firms". In this technology all workers are ex-ante identical, and their productivity depends on the amount of effort they exert. Workers dislike to expend effort, and their effort level is not verifiable. This creates a standard moral hazard problem. To provide incentives, firms are engaged in monitoring. Monitoring precision is costly and non verifiable, a fact that creates another moral hazard problem between workers and employers.[3] The ensuing Nash game between workers and employers, where the former choose effort and the latter monitoring intensity, results in a bonus scheme. The scheme optimally trades off the workers' rent against efficiency.

The analysis is framed in a dynamic setting. The economy is populated by infinitely lived risk neutral households that maximize their discounted expected utility. Each household chooses every period whether its members will be self-employed or employees. In the latter case, the household faces the bonus scheme and selects its members' effort level. Households allocate income between consumption and saving in the standard way.

Firms hire capital and decide on the monitoring intensity every period so as to maximize profits. The optimal structure of the bonus contract that emerges turns

[2] Other models with informational rents could probably be used to generate similar results. See the conclusion for a brief discussion.

[3] The resulting double moral hazard problem is different from the one usually analyzed in the labor economics literature. In particular using a tournament would not resolve the issue addressed here.

out to depend on the amount of capital hired by the firms. This implies that the equilibrium effort level and the number of employees also depend on that amount of capital.

The growth process out of steady state is characterized by increases in capital and in labor productivity. Specifically, higher amounts of capital increase the demand for labor. Since the additional labor needs to be enticed away from self-employment, labor contracts have to become more attractive, reflecting the higher productivity of workers in their alternative occupation. The "better" labor contracts entail higher bonuses and more monitoring, and thereby induce higher effort. Consequently, as the economy grows, more workers become employees, and productivity increases without any technical progress or change in human capital.[4]

In order to assess the potential quantitative magnitudes of these effects, we solve the model numerically using plausible parameter values. We show that our numerical model can mimic quite well productivity growth, increases in monitoring costs, and the relationship between productivity and the corporate employee share that have been documented in the literature.

The paper starts with a short presentation of some stylized facts. Next, present the model. We discuss the static problem of the workers and of the firms and derive the optimal bonus contract. We also show that the contract is consistent with the dynamic optimization problem of the households. We then parameterize some key functions in our economy, and derive the equilibrium conditions for that specific case. We conduct some comparative static experiments on the steady-state of the

[4]Once the economy reaches a steady state this process stops. We choose to abstract from sustained growth in order to highlight the interrelationship between the changes in capital and the incentive contracts.

economy and asses the impact of particular parameters governing the monitoring technology on effort and productivity. Finally, we numerically evaluate a dynamic equilibrium path and discuss its properties. The last section of the paper briefly discusses the scope of our results.

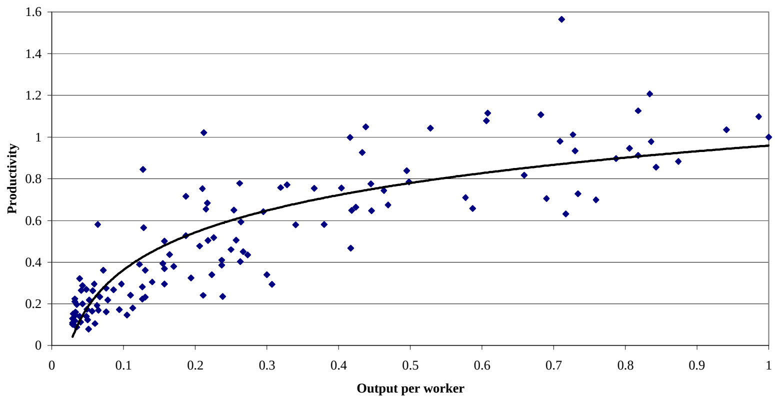
2. Some Stylized Facts

There is by now a large body of knowledge, both empirical and theoretical, that focuses on the large cross-county differences in per-capita output and productivity. This is the key observation that drives our model. However, our model generates in addition time-paths and cross-economy relationships of some variables that, while documented for various purposes, have not necessarily been at the focus of the growth literature. This short section aims at providing a summary of these observations.

Hall and Jones (1999) compute productivity indices (relative to the US) and per-capita output of 127 countries. They (and many others) find large differences among countries, and a very clear (possibly non-linear) relationship between output per-worker and productivity, as depicted in Figure 1(see also Hall and Jones, Figure 1):[5]

[5] The simple correlation between productivity and output in this data set is 0.85. The data can be found at the site http://elsa.berkeley.edu/users/chad/datasets.html

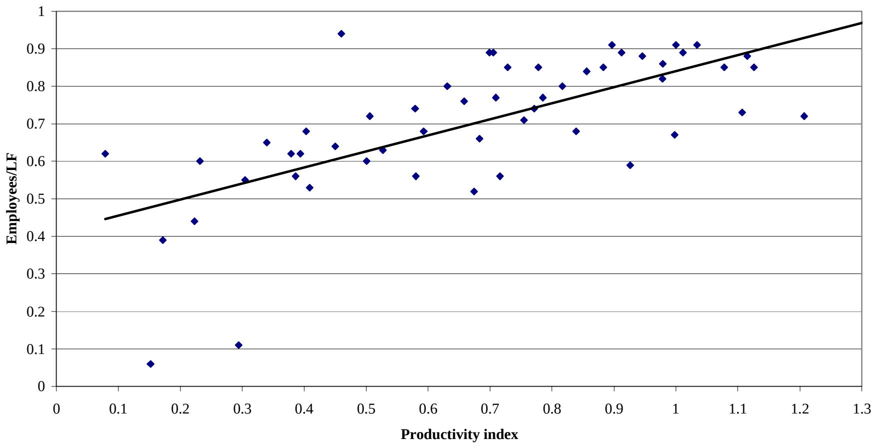
Figure 1:
Output and Productivity



We have augmented the Hall and Jones data with two features related to the labor market in various economies, as reported in Bernanke and Gürkaynak (2001). Specifically, Table X of that paper reports the corporate employee share in the labor force for many countries, and several (highly correlated) measures of the labor share in income that correct for possible under-reporting of income of workers who are outside the corporate sector (self-employed and others).[6] Figure 2 shows the relationship between the Hall and Jones productivity measure and the corporate employee share. As can be seen, these two variables are quite highly correlated (a simple correlation of 0.68).

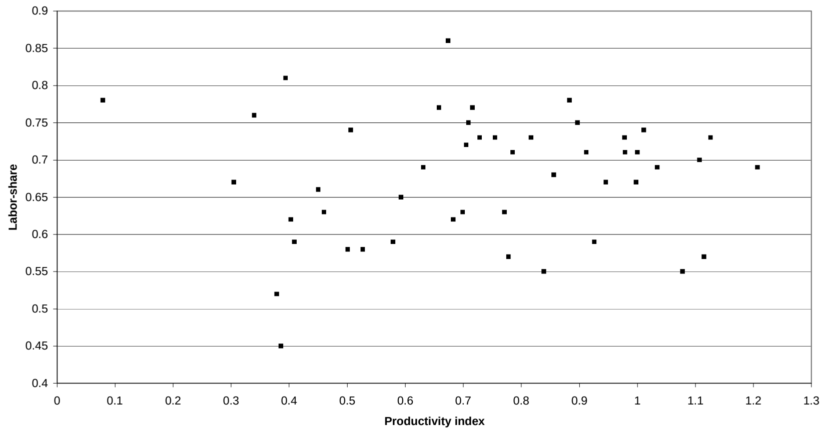
[6] Bernanke and Gürkaynak report only their calculations for countries whose corporate labor force share exceeds 50%. For countries with low fraction of corporate employees they got very high labor shares in income, which they think are unreasonable. Our model predicts that under certain circumstances, there may indeed exist a very high correlation between the fraction of workers outside the corporate sector and labor share in income.

Figure 2:
Productivity and Employment



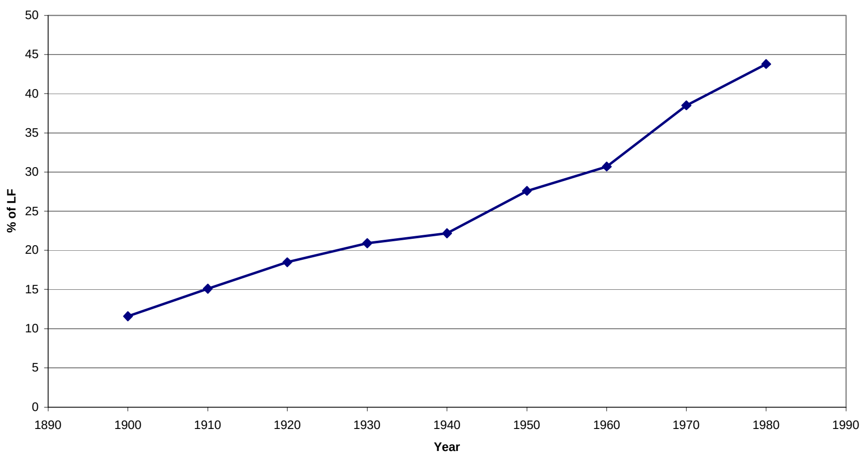
In contrast, there is basically no relationship between the labor share in income and the Hall and Jones productivity measure (simple correlation of 0.08), as Figure 3 shows:

Figure 3:
Productivity and Labor-share



Finally, there is some evidence on the role of management in a growing economy. Radner (1992) presents evidence concerning the increased *share* of resources used for the purpose of "managing in the economy".[7] Figure 4 replicates Radner's Table 6, that reports the fraction of managers in the (experienced) US labor force between 1900 and 1980.

Figure 4:
Managers in the US



3. The model

We consider a single good, discrete time economy with a constant population of infinitely lived households indexed on the unit interval by h. We describe the

[7]Radner's partial list of "what managers do" includes, of course, "monitor the actions of other firm members" (p. 1388).

households in some detail, before we specify the two technologies with which the good can be produced

3.1. Households

Each household h consists of a continuum of identical members indexed over the unit interval. The household owns $k_t(h)$ units of capital at the beginning of period t that are inelastically supplied to the capital market at the rental rate r_t. In addition, each member of the household is endowed with 1 unit of labor per period that is inelastically supplied. Every member i of the household may exert effort $\epsilon_t^i(h)$. Effort may potentially affect that member's labor productivity in a way to be specified below. However, household members are not decision-making units. They are agents of the household and carry out its decisions, in particular those concerning effort.[8]

All households in the economy have identical preferences. At every period, they are assumed to care (positively) about their aggregate consumption, x_t, and (negatively) about the amount of effort exerted by each of their members, ϵ_t. [9] Households are assumed to be maximizing the discounted stream of momentary

[8] The goal of this structure is to remove any idiosyncratic uncertainty at the household level (see Shi [1998] for a similarly motivated specification). Specifically, one may think of the household members as "machines" that are "programmed" by the household and have no will of their own. Alternatively, one may think of the household as an institution that can fully and costlessly monitor its members.

[9] Clearly, one may also think of the household preferences as the aggregate over individual member preferences, defined over their consumption and effort, i.e.

$$\int u(x_t^i, \epsilon_t^i)di \ .$$

However (3.1) follows since $x_t^i = x_t$ and $\epsilon_t^i = \epsilon_t$ for all members $i \in [0, 1]$ of the household.

utility:

$$\sum_{t=0}^{\infty} \eta^t u(x_t, \epsilon_t) \tag{3.1}$$

where η denotes the discount factor. For the momentary utility, we specify

$$u(x_t, \epsilon_t) = x_t - c(\epsilon_t) \tag{3.2}$$

where the function $c(\epsilon)$ measures the disutility of effort. The function $c(\cdot)$ is assumed to be increasing and convex with $c(0) = 0$. In addition, we impose a minimum subsistence level per member, denoted by $\underline{x}$.[10]

Labor can be used in either one of two technologies. In one of them, the workers will be referred to as being "self-employed" and in the other as "employees". If self-employed, a member of household h produces output $y(h)$ at no effort cost.[11] Without loss of generality, households are ordered in such a way that $y'(\cdot) > 0$.

Alternatively, a household may decide to send its members to the labor market as employees. Once employed, each member exerts the household determined effort level ϵ, and obtains a corresponding compensation in terms of output. Despite the fact that members of distinct households have different productivity if self-employed, they are assumed to be equally productive as employees.[12]

The budget constraint of the household depends on the employment status of

[10] The linear specification of the utility function is used for parsimony to keep the subsequent employment contract simple. The subsistence level is introduced to generate more realistic dynamics in the face of that linearity.

[11] Obviously, including effort costs would not change anything as $y(h)$ could be interpreted as production net of these costs. Furthermore, the assumption that the self-employed technology does not require any other input is made purely for convenience and does not affect the conclusions.

[12] Relaxing this assumption would considerably complicate contracts as they would have to be type-dependent. However, this would not substantially alter the model's implications.

its members. We discuss the specifics after the introduction of the optimal bonus scheme.

3.2. Firms

Firms are employing capital and labor. The effectiveness of labor provided by an employee depends on the effort ϵ exerted by that employee. Anticipating that it will be to the firms' advantage to provide equal effort incentives across workers, we write the production function of firms as $F(K, \epsilon L)$, where K and L denote the per-firm capital and labor employment.[13] We make standard assumptions on the production function. In particular, it is assumed that the production function is homogeneous of degree 1 in both arguments.

3.3. The double moral hazard problem

In this subsection, we solely focus on the contractual game between a representative household and a firm. We assume that the game has to be played every period independently of the past. In doing so, we rule out long term contracts and any reputation effect either on the part of firms or households.[14]

Our key assumption is that workers' effort is not directly contractible. As a result, households' behavior is affected by problems of moral hazard. On the other hand, it is assumed that firms can generate contractible information on effort. This introduces the ability to mitigate the moral hazard problem through the use of

[13] Assuming effective labor is additive across workers, production can be written as $F(K, \int_L \epsilon(h)dh)$ where L is the set of employees of the firm.

[14] Obviously, this restriction is a very simple way to generate rents. In general, any modelling device that sustains the existence of rents (or risk premia) will lead to organizational transaction costs that underly our analysis.

proper incentives. More concretely, we assume that every worker is emitting noisy signals related to the effort level. At some costs, these signals can be measured and made verifiable. Accordingly, these signals become contractible. However, the fact that signal measurements are costly to the firm introduces a further moral hazard problem, this time on the part of employers. Our assumption here is that though information is verifiable, the precision of that information is not.[15] This double moral-hazard problem is resolved through a game which determines the precision at which the signals will be measured and the extent to which they will be used in the labor contract.

In order to derive the optimal decision of the firm in the appropriate game, we assume here that in each period households maximize their income net of effort costs. In the next subsection, we show that under the derived contract, this presumed behavior is consistent with the preference specification as given in (3.1) and (3.2). Because the same game is repeated every period, we omit the time index whenever no confusion may result.

The firm faces the problem of how much effort to induce. This decision entails a choice of an employment contract and of the amount of resources it allocates to the process of measuring the emitted signals. The latter determines the precision at which these signals are measured, which is parameterized by θ.

At this point, we can draw from existing results in the literature. In particular, it is known that in the current setting – due to the risk-neutrality of both parties –

[15] To give a concrete example, suppose that a university contract promises a positive tenure decision whenever a tenure commission presents two ‘good’ reports from external qualified academics. The precision of such a scheme is obviously manipulable, since a tenure commission could always ask for more than two reports and only present those reports that are found advantageous.

optimal incentive contracts are of the bonus type, where a worker receives a fixed payment A, and depending on the realization of the measured signal, a bonus B.[16] These results depend on the aforementioned assumption, that relates the distribution of the signals to the worker's effort. Moreover, consistent with the moral hazard problem of the firm, it is assumed that this distribution also depends on the precision of measurement.

Since the optimal contract is of the bonus type, the measured signals can be aggregated to a binary random variable, $\chi \in \{0, 1\}$, where the worker receives the bonus if $\chi = 0$. We denote

$$p(\epsilon, \theta) = \Pr[\chi = 0 \mid \epsilon, \theta] \ . \tag{3.3}$$

We assume that $p_\epsilon > 0$ and $p_{\epsilon\epsilon} < 0$. Heuristically the first requirement means that $\chi = 0$ constitutes a 'favorable' information with respect to the agent's action in the sense of Milgrom (1981). The concavity requirement guarantees that the agent's problem is well behaved. The conditions are necessary and sufficient for any action to be implementable with the binary signal χ. [17]

Finally, we let $\phi(\theta)$ denote the resource cost of precision per worker. Regarding precision, we assume $p_\theta < 0, p_{\theta\theta} > 0$ and $\phi_\theta > 0, \phi_{\theta\theta} > 0$. The conditions on the first derivative are not real restrictions. They would naturally follow if the information acquisition problem of firms was to be fully modelled. The convexity

[16] See Park [1995], Kim [1997] and Demougin and Fluet [1998].

[17] The derivative requirements on the probability distribution of the binary variable impose conditions on the underlying information structure. Demougin and Fluet [1998] have shown that if the underlying information system satisfies the Monotone Likelihood Ratio Condition (MLRC) and the Convexity of the Density Function Condition (CDFC), then the required conditions are indeed satisfied.

requirements guarantee that the first order conditions are sufficient.

The timing of the game between firms and households (within a period) is as follows. Firms offer a bonus contract $\{A, B\}$ where A denotes the fixed payment and B the bonus part of the contract. In addition, firms announce a precision level θ by which they intend to measure the signals. As we assume that θ is not contractible, the double moral hazard problem requires the firm to make a credible announcement. Households either decide to have their members work for firms or to remain self-employed. "Employee-households" select their level of effort, given the announced precision. The firms select the precision, which, in equilibrium, is the same they have announced. Finally, signals are observed and payments are made.

3.4. The bonus contract

For the subgame where firms select precision and households make a choice of effort, we use the Nash equilibrium concept. Starting with the problem of the household, suppose it has chosen to send its members to work for firms. That household faces a bonus contract $\{A, B\}$ and expects the firm to implement a precision level θ. The household chooses effort to maximize utility derived from the employment contract. Analytically, it solves

$$\max_{\epsilon} \quad A + Bp(\epsilon, \theta) - c(\epsilon) \ . \tag{3.4}$$

From the foregoing, the first-order condition is sufficient. Rewriting that condition yields the bonus which the firm must pay to induce effort ϵ, given the precision level θ:

$$B = \frac{c'(\epsilon)}{p_\epsilon(\epsilon, \theta)} \ . \tag{3.5}$$

Given that each worker works for a firm according to the bonus scheme $\{A, B\}$, and given that the firm expects each worker to produce the effort ϵ, the firm will choose precision, θ, to minimize its expected costs – i.e. the sum of precision costs plus expected bonus and fixed payments to workers. Hence, a firm will solve

$$\min_\theta \quad A + Bp(\epsilon, \theta) + \phi(\theta) \ . \tag{3.6}$$

Again, the first-order condition is sufficient, yielding:

$$Bp_\theta(\epsilon, \theta) + \phi'(\theta) = 0. \tag{3.7}$$

Given a contract $\{A, B\}$, the solution to the Nash game is a pair (ϵ, θ) that solves (3.5) and (3.7). [18]

3.5. The overall problem of the firm

In this subsection, we embed the contractual game in the larger context of the firm's overall decision problem. At this stage, in addition to determining the bonus contract – thereby inducing the desired effort – the firm must also select precision, capital and employment. The firm takes as given the rental rate of capital. In addition the firm faces a reservation utility for households. Altogether, the firm's problem can be written as:

[18] Note that the solution may not be unique. This, however, is not a problem since by announcing the contract the firm can select the best equilibrium for itself.

$$\max_{\epsilon,\theta,A,B,K,L} \quad F(K,\epsilon L) - [A + Bp(\epsilon,\theta) + \phi(\theta)]\, L - rK + (1-\delta)K \tag{3.8}$$

$$Bp_\epsilon(\epsilon,\theta) - c'(\epsilon) = 0 \tag{3.9a}$$

$$A + Bp(\epsilon,\theta) - c(\epsilon) \geq \overline{y} \tag{3.9b}$$

$$Bp_\theta(\epsilon,\theta) + \phi'(\theta) = 0 \tag{3.9c}$$

where δ is the depreciation rate, and $\overline{y}$ denotes the reservation utility of worker households. The constraints (3.9a) and (3.9b) are the household's incentive and participation conditions and (3.9c) is the credibility requirement for the firm's announcement of precision.

In the remaining, it is advantageous to use the homogeneity of the production function to rewrite the objective function of the firm in per worker terms. Specifically denote

$$Lf(k,\epsilon) \equiv F(kL,\epsilon L) \ ,$$

where k measures the capital labor ratio. Substituting this definition in the firm's problem and abstracting from the employment decision, we can rewrite problem (3.8). Since the firm takes $\overline{y}$ as given, it is easily seen that (3.9b) will be just binding. Therefore A can be eliminated from the firm's problem. Similarly, B can be eliminated by using the constraints (3.9a) and (3.9c). Altogether the optimization problem of the firm can be reduced to a Lagrange problem:

$$\max_{\epsilon,\theta,k} \ \mathcal{L} = f(k,\epsilon) - [c(\epsilon) + \overline{y} + \phi(\theta)] + (1-\delta-r)k + \lambda\left(\phi'(\theta) + \frac{p_\theta(\epsilon,\theta)}{p_\epsilon(\epsilon,\theta)}c'(\epsilon)\right) \tag{3.10}$$

3.6. The household's problem revisited

When deriving the optimal bonus contract above, $\mathcal{C} = \{A, B, \theta\}$, we have assumed that households care about the expected income net of effort costs of each of their members (see (3.4)). Here we show that under the derived bonus contract this assumption is consistent with the dynamic optimization problem of households.

In general, every household decides each period on the employment status of its members, possibly on effort, and on saving and consumption. Saved income turns into capital next period and will be rented out in the capital market. The resulting optimization problem of household h becomes:

$$\max_{\{\epsilon_t, x_t, k_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \eta^t [x_t - c(\epsilon_t)] \tag{3.11a}$$

$$x_t + k_{t+1} - r_t k_t = \begin{cases} A_t + B_t p(\epsilon_t, \theta_t) & \text{if employed} \\ y(h) & \text{if self-employed} \end{cases} \tag{3.11b}$$

$$x_t \geq \underline{x} \tag{3.11c}$$

where the household is assumed to have perfect foresight over future rental rates and employment contracts and k_0 is given. We denote the solution to the problem by the sequence $\{k_{t+1}(h), \epsilon_t(h), x_t(h)\}_{t=0}^{\infty}$.

From the optimization problem it should be evident that the following holds.

Lemma 3.1. *Given a contract $\mathcal{C}_t = \{A_t, B_t, \theta_t\}$ in period t, the effort level chosen by a household of employees is*

$$\epsilon_t = \arg\max_{\epsilon} \; A_t + B_t p(\epsilon, \theta_t) - c(\epsilon) \; . \tag{3.11l}$$

Furthermore, the fraction of households that choose the "employee" status is given every period by z, where z solves:

$$y(z) = \max_{\epsilon} \; A_t + B_t p(\epsilon, \theta_t) - c(\epsilon). \tag{3.11m}$$

Thus, due to the linearity of the utility function, despite the dynamic structure households maximize every period their income net of effort costs.

4. A specification

4.1. Monitoring

The monitoring part is the least standard in our paper. Therefore, the specification used in the sequel needs special motivation. Consider an environment where an agent in the course of carrying out his work emits signals that are related to his effort. In particular, these signals take the value 0 or 1 where 0 is the "favorable" signal. Let Y denote the number of unfavorable signals. We assume that Y is generated by a Poisson process. The density parameter of that process (i.e. the expected value of unfavorable signals) is negatively related to the agent's effort. In particular, we specify that relationship to be $\epsilon^{-\nu}$, where ν is the elasticity of the density parameter with respect to effort. We assume that in addition to the process generated by the agent's effort, there is another independent Poisson process with a density parameter m, that interferes with the effort-related process. The sum of the two processes is a Poisson process, with a density parameter $m + \epsilon^{-\nu}$.

Let

$$a(\epsilon, m) = \exp(-m - \epsilon^{-\nu}) \tag{4.1}$$

denote the probability that no adverse signal is observed when all signals are detected.

Suppose that a monitoring device samples a proportion θ of the signals. The probability that no adverse signal is observed within the sample is, therefore, $a(\epsilon, m)^{\theta}$.

We already know from the foregoing that in the type of environment just described the optimal labor contract, when only signals are observed, is of the bonus type. Moreover, Demougin and Fluet [2001] have shown that for the efficient contract, the bonus should be paid only when no unfavorable signal is detected. Thus, in this particular environment the probability of receiving the bonus is simply

$$p(\epsilon, \theta) = a(\epsilon, m)^{\theta} \tag{4.2}$$

4.2. Production and costs

We assume that the cost functions are represented by

$$\phi(\theta) = \phi \cdot \theta^{\alpha}, \ \alpha > 1 \tag{4.3a}$$

$$c(\epsilon) = c \cdot \epsilon^{\beta}, \ \beta > 1 \tag{4.3b}$$

Finally, the production technologies are specified to be a standard Cobb-Douglas function for the corporate sector and an exponential function for the self-employed

$$f(k,\epsilon) = Tk^{\gamma}\epsilon^{1-\gamma} \quad 0 < \gamma < 1 \tag{4.4a}$$

$$y(z) = y_0 z^{\mu} \quad 0 < \mu \tag{4.4b}$$

Where T and y_0 are positive constants.

5. Equilibrium

Given K_0, an equilibrium is a sequence of $\{K_{t+1}, X_t, \mathcal{C}_t, \epsilon_t, \overline{y}_t, z_t, k_t, r_t\}_{t=0}^{\infty}$ where $K_{t+1} = \int k_{t+1}(h)dh$ and $X_t = \int x_t(h)dh$ denote aggregate capital and consumption, such that

(i) firms solve problem (10),

(ii) households solve (11),

(iii) firms' profit are zero,

(iv) $k_t = K_t/z_t$,

(v) $\overline{y}_t = y(z_t)$.

Using the above specification, a steady state of the economy is given by the following set of conditions:

$$T(1-\gamma)k^{\gamma}\epsilon^{-\gamma} - \beta c\epsilon^{\beta-1} - \lambda\beta c\epsilon^{\beta-1}\left[(1+\frac{\beta}{\nu})m\epsilon^{\nu} + \frac{\beta}{\nu}\right] = 0 \tag{5.5a}$$

$$T\gamma k^{\gamma-1}\epsilon^{1-\gamma} + (1-\delta-r) = 0 \tag{5.5b}$$

$$-\phi\alpha\theta^{\alpha-1} + \lambda\phi\alpha^{2}\theta^{\alpha-1} = 0 \tag{5.5c}$$

$$\alpha\phi\theta^{\alpha} - \frac{1+m\epsilon^{\nu}}{\nu}\beta c\epsilon^{\beta} = 0 \tag{5.5d}$$

Furthermore, the household incentive and participation constraints yield:

$$B\theta\nu\epsilon^{-\nu-1}\exp\left[-\theta(m+\epsilon^{-\nu})\right] - \beta c\epsilon^{\beta-1} = 0 \tag{5.6a}$$

$$A + B\exp\left[-\theta(m+\epsilon^{-\nu})\right] - c\epsilon^{\beta} = \overline{y} \tag{5.6b}$$

Finally, we also have three market clearing conditions:

$$Tk^{\gamma}\epsilon^{1-\gamma} - A - B\exp\left[-\theta(m+\epsilon^{-\nu})\right] - \phi\theta^{\alpha} + (1-\delta-r)k = 0 \tag{5.7a}$$

$$r = \frac{1}{\eta} \tag{5.7b}$$

$$y(z) = \overline{y} \tag{5.7c}$$

Equation (5.7a) is the zero profit condition. Condition (5.7b) requires that in the steady state the market clearing interest rate be given by the household discount factor. Finally, (5.7c) determines the opportunity cost of the marginal household in the firm sector.

The overall system is block recursive and can be easily simplified. First, we eliminate r and $\overline{y}$ from (5.7b) and (5.7c). Second, equation (5.5c) implies that

$\lambda = 1/\alpha$. Using the above results in (5.5a) and in (5.5b), the system reduces to:

$$T(1-\gamma)k^{\gamma}\epsilon^{\gamma} - \frac{\beta c \epsilon^{\beta-1}}{\alpha}\left[(1+\frac{\beta}{\nu})m\epsilon^{\nu} + \frac{\beta}{\nu} + \alpha\right] = 0 \tag{5.8a}$$

$$T\gamma k^{\gamma-1}\epsilon^{1-\gamma} - (\frac{1}{\eta} - (1-\delta)) = 0. \tag{5.8b}$$

From these equations, we obtain ϵ and k, and θ follows from (5.5d). Finally, A, B obtain from (5.6a)-(5.6b).

6. Comparing steady-states

In this section, we perform some steady state comparisons with respect to changes in the equilibrium interest rate and the effectiveness of the monitoring technology. The first exercise allows us to examine the relationship between changes in the interest rate and some key features of the economy, in particular effort and productivity.[19] The second exercise focusses on variations in the monitoring environment and will be used to show that these changes can account for large differences in the induced productivity.

6.1. Changes in the interest rate

In order to simplify notation, we rewrite the firms' problem. We solve for the precision variable from (5.5d), thus eliminating both θ and the constraint. The firms' problem then becomes:

[19] The interest rate is, of course, endogenous. Changes in the interest rate may be due to changes in the subjective discount factor or the depreciation rate. In addition, one may introduce risk to induce such changes.

$$\max_{\epsilon,k} \quad \pi = Tk^{\gamma}\epsilon^{1-\gamma} - c\epsilon^{\beta}\left[1 + \frac{1+m\epsilon^{\nu}}{\alpha\nu}\beta\right] - \overline{y} + (1-\delta-r)k \ . \tag{6.9}$$

Writing the first-order conditions in ϵ and k, we obtain from implicit differentiation:

$$\epsilon_r = -\frac{\pi_{\epsilon k}}{\det H} \leqslant 0 \text{ and } k_r = \frac{\pi_{\epsilon\epsilon}}{\det H} \leqslant 0 \ , \tag{6.10}$$

where H is the relevant Hessian. The signs follow from the local concavity at the maximum – which yields $\det H > 0$ and $\pi_{\epsilon\epsilon} < 0$ – and because capital and effort are complements, i.e. $\pi_{\epsilon k} > 0$. We summarize our conclusion in the following result:

Result 1: *Lower steady-state interest rates are associated with higher effort.*

The result is very intuitive. Lower interest rates are associated with higher capital labor ratios and the higher effort follows from the complementarity assumption. Thus, other things being equal, we conclude that a highly capitalized economy (namely, an economy with a high capital-labor ratio) should also be characterized by high effort of employees. The latter implies high total factor productivity.

Next, we turn to the labor contract required to induce the desired effort, ϵ. From (5.5d), we observe that ϵ and θ move in the same direction, thus, $\theta_r < 0$. However, from the point of view of the household, what really matters is the impact of these changes on its expected bonus which we refer to as *power* and denote with P. From (5.6a), after some manipulation, it is easy to show that $P_r < 0$. We summarize these observations as:

Result 2: *Lower steady-state interest rates are associated with higher precision and higher contract power.*

Finally, in order to obtain the effect of a change in the interest rate on the fraction of workers employed, notice that firms' profits are a decreasing function of r. Thus, to keep profits at zero, $\overline{y}$ must also be decreasing in r. Since y is increasing in z, we obtain:

Result 3: *Lower steady-state interest rates are associated with a larger fraction of the labor force working for the "corporate sector".*

Altogether, differences in the interest rate induce co-movements in the capital-labor ratio, in employment and in effort. Consequently, total factor productivity may be changing in the "corporate sector" independently of any technical change in that sector.

6.2. Changes in the monitoring environment

We represent changes in the monitoring environment as variations in m. These variations affect the ability of the monitoring device to detect the underlying signals emitted by the worker. Interferences with this ability to accurately measure the workers' signals imply increases in m, and may emerge if, for example, information that is extraneous to that worker's tasks is taken into account.[20]

From (6.9) we see that the effective marginal costs of effort are everywhere increasing in m. Thus we can derive along the exact same line as in the foregoing subsection the effect of changes in m. The consequences for the steady states are summarized in the following result.

Result 4: *More informative measures of steady state effort are associated with higher capital-labor ratios, more effort, higher monitoring precision and power,*

[20] One may think of issues like political affiliation, sex, ethnicity. Legal requirements may also interfere with precision.

and a higher fraction of the labor force working for the "corporate sector".

7. The Model's Performance

7.1. The Baseline

The baseline economy's parameters are chosen in an attempt to emulate some common characteristic of a "typical" economy (on a yearly basis). In particular, we aim at achieving a labor share of roughly 70% of output, and a share of "employees" of roughly 70% of the labor force.[21] We also aim at a "reasonable" saving rate of roughly 20% of output. Some of the parameters are set at their by now standard values: the depreciation rate, δ, is set at 0.08, the discount factor, η, is 0.95.

The remaining parameters were chosen by trial and error, as follows. For the monitoring cost, we have $\phi = 2$, and $\alpha = 1.45$. For the effort disutility, we set: $c = 0.1$ and $\beta = 1.45$. The effort detection probability is assumed to be generated by ϵ with $\nu = 1$ and $m = 0$. The production function in the "corporate sector" is characterized by $T = 0.7$ and a standard value of 0.3 for γ. The production function for the self-employed is specified with $y_0 = 2$ and $\mu = 2$.[22]

[21] The corresponding averages in the Bernanke and Gürkaynak sample are 70% for the share of corporate employees and 67.5% for the share of labor in income.

[22] While this value of μ may seem to be "large" in terms of its implication for the average productivity of self-employed workers, it is generating reasonable implications for the evolution of their productivity in comparison with the rest of the economy.

Table 1: The Baseline Steady-State

Variable	
Per-capita Total Output ($\overline{y}$)	2.64
Saving Rate	0.20
Effort (ϵ)	4.97
θ	0.63
z	0.68
$p(\epsilon, \theta)$	0.88
$k/\overline{y}$	2.46
$w/\overline{y}$[1]	0.67
$m/\overline{y}$[2]	0.26
$y/\overline{y}$[3]	0.83
TFP_y[4]	3.07
TFP_z[5]	1.42

Notes:

[1] Share of employee and self-employed compensation in total output

[2] Share of monitoring costs in total output[23]

[3] Share of "corporate sector" in total output

[4] Total factor productivity in "corporate sector"

[5] Output per worker in "self-employed" sector.

[23]Notice that the monitoring costs are *not* counted as part of the economy's total output.

7.2. Monitoring Technology

To study the impact of the monitoring technology, we run two numerical experiments. The first involves changing the impact of a given level of effort on the likelihood of receiving a favorable/unfavorable signal through the value of ν. The second experiment involves the addition of the external noise, m, to the detection technology. We examine in particular the resulting effect on output, productivity, share of employees in the labor force and the labor share in income. We compare the results of the experiments to the performance of these variables in the data, and draw some tentative conclusions on the potential source of cross-country differences.

First, we allow ν to range between 0.8 and 2.4 (at steps of 0.1).[24] We use the output and productivity results of the "best" economy ($v = 2.4$) as the standard of comparison, and report in the following figures the performance of the other economies along these measures in relative terms.

Figure 5 resembles the actual data (see Figure 1). Both relative measures of productivity increase as the relative output (per-worker) increases. Moreover, the relationship is non-linear, and quantitatively similar to the analogous segment of Figure 1. However, these changes in ν *alone* cannot account for the entire range of differences found in the data.[25]

[24] This is the range for which the model yields interior solutions.

[25] While this example cannot match the 7.7 factor Hall and Jones [1999] find for the difference between the *U.S.* productivity and that of Niger, our model gets the slope of Figure I in their paper (on page 90) about right. There, a factor of 4 in output per worker is associated with a factor of about 2 in total factor productivity.

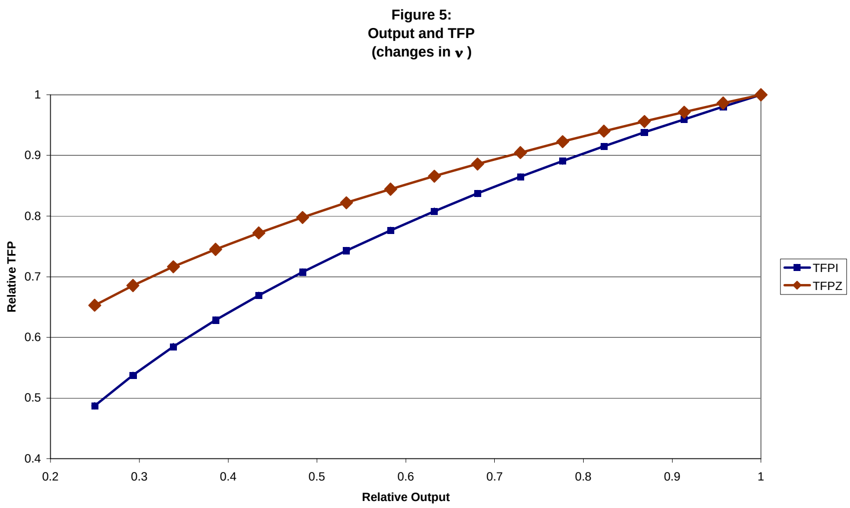
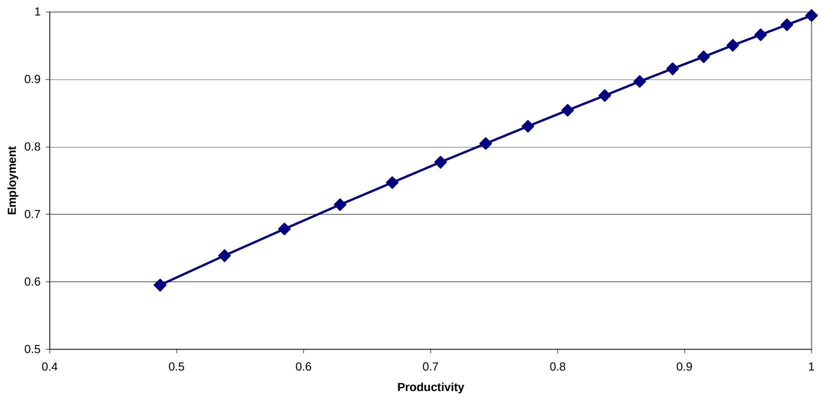


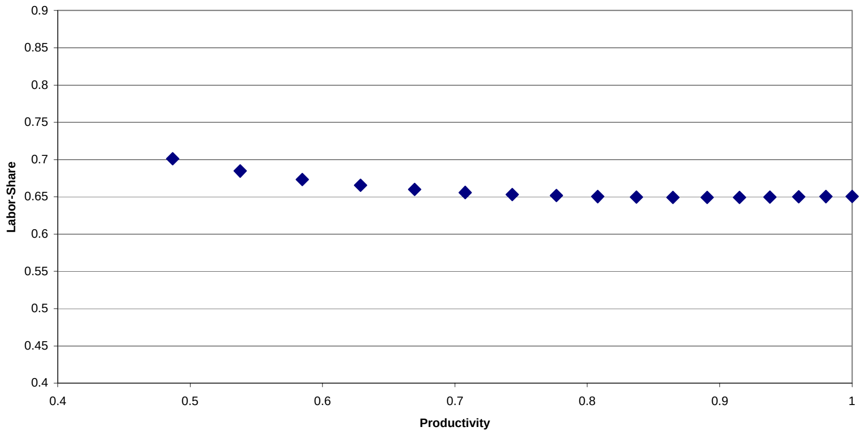
Figure 6 displays a strong association between the productivity index and the fraction of corporate employees in the labor force. This is clearly in line with the data, as shown in Figure 2. However, from the quantitative point of view, the model generates "too much" employment in the "corporate sector", and in fact, at the highest value of ν, the entire labor force becomes "employed".

Figure 6:
Productivity and Employment
(changes in n)



Finally, Figure 7 depicts the relationship between the labor share in income and productivity:

Figure 7:
Productivity and Labor-Share
(changes in v)



This figure shows that the labor share has a slight inclination to decline as productivity increases, but the relationship is overall weak, as is the case in Figure 3.

For the purpose of comparison, we let also m vary from 2 (the worst case) to 0, at steps of 0.1. The value of ν is fixed at 1. The results are shown in Figures 8-10.

Figure 8:
Output and TFP
(changes in m)

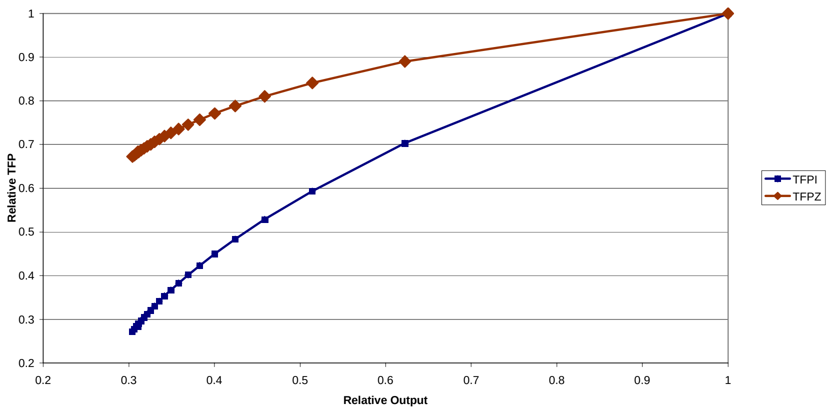


Figure 9:
Productivity and Employment
(changes in m)

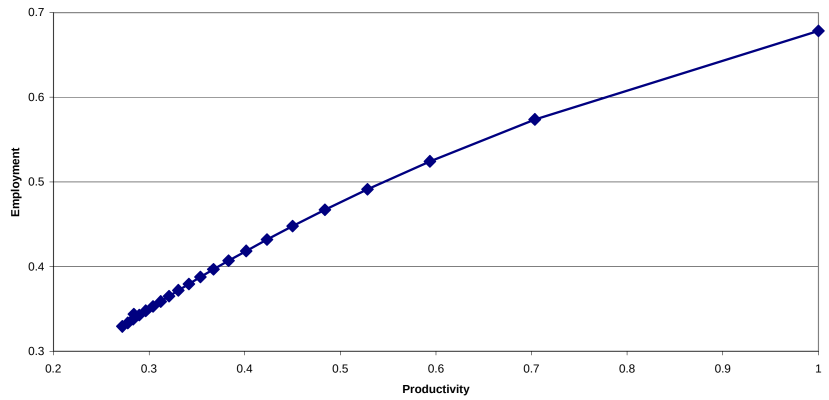
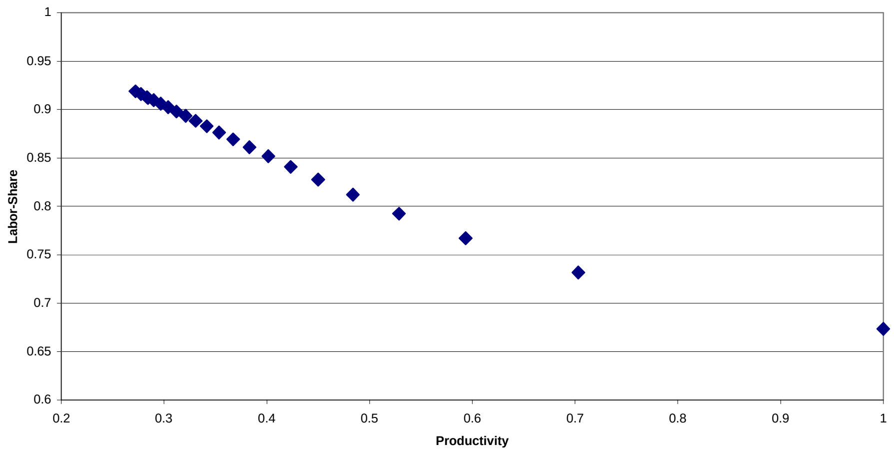


Figure 10
Productivity and Labor-Share
(changes in m)



While Figures 8 and 9 resemble Figures 1 and 2, Figure 10 describes a dramatic decline in the share of labor in output as productivity increases. This is a clear contradiction to the facts, as shown in Figure 3.

The example shows that the model can potentially identify the source of differences among countries. In particular, the model implies that these differences cannot be ascribed to the *noisiness* of the signal that reaches the detection apparatus. Rather, the model indicates that the differences are due to the *sensitivity* with which the apparatus detects the signal and its impact on the ability of labor contracts to induce effort.[26]

7.3. Dynamics

We turn to the growth path of the base-line economy. The economy is started with a third of its steady-state capital. We set $\underline{x}$ (the subsistence level) to 1.1.[27] The economy reaches the steady-state after 55 periods. We describe first the economy's growth performance, through Figure 11.

[26] While disturbances to the detection apparatus that are represented by m may be associated with the interference of the political system in the evaluation of workers, the parameter ν may reflect societal attitudes towards equity and competition.

[27] This parameter has no implications for the steady-state. The choice is motivated by the desire to generate relatively long time series for the growth path.

Figure 11:
Growth Rates

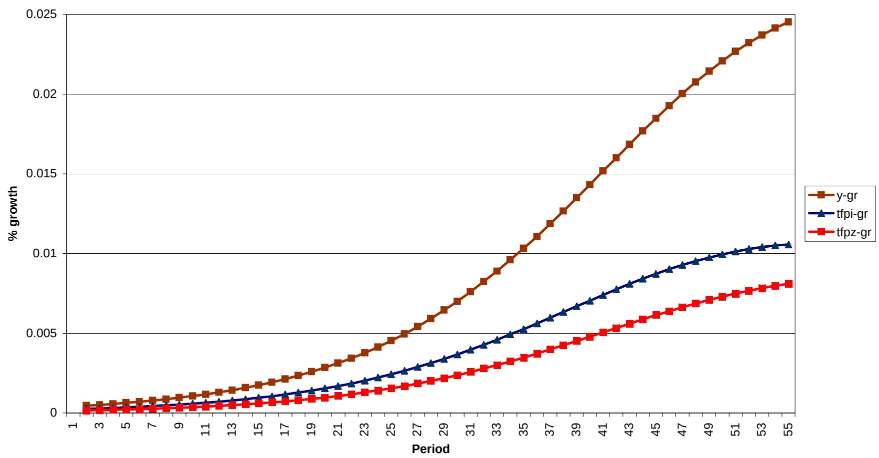
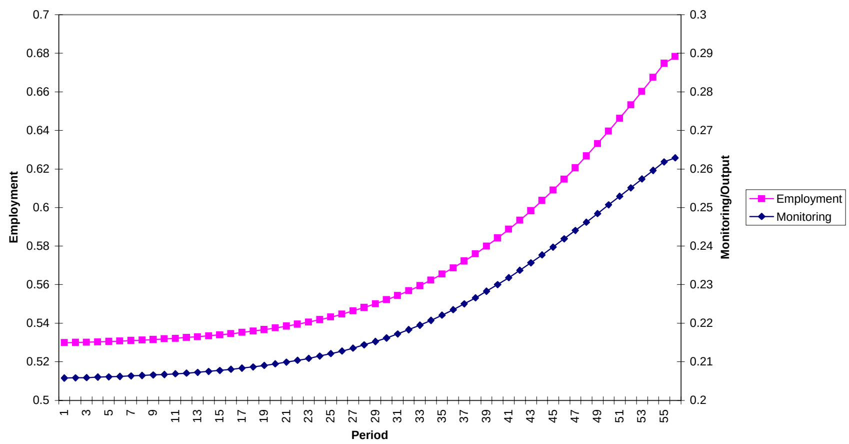


Figure 11 depicts the growth rates of output as well as of the total factor productivity in the "corporate sector" and of the output per worker in the "self-employed" sector. As can be seen from the figure, the growth rates are all accelerating towards the steady-state. The total factor productivity growth rate accounts for a bit below one half of the output growth rate. The productivity growth is due to the fact that as the economy is accumulating capital, more workers are needed for the "corporate sector". These workers have to be enticed away from self-employment. As the productivity of the marginal self-employed worker increases, a better contract has to be offered to the corporate workers. This, in turn, entails more monitoring and higher productivity.

Finally, in Figure 12 we show the evolution of the fraction of workers employed in the "corporate sector" and the monitoring costs relative to output. The figure clearly shows that the need to entice more workers into the "corporate sector" is indeed associated with higher monitoring costs. This result corresponds closely with Radner's (1992) findings summarized above. Both in reality and in the model, the growth process requires an increasing allocation of resources to monitoring and "management".

Figure 12:
Employment and Monitoring



8. Conclusion

This paper generates total factor productivity gains that are unrelated to any technological progress. In fact, production technologies are kept constant throughout the analysis. However, out of steady-state the economy is accumulating capital. The workers who use this capital need to be enticed away by the "corporate sector" from an alternative occupation. The productivity of the marginal worker in that alternative occupation is assumed to increase as more workers are employed. This forces wages in the "corporate sector" to increase. To justify the higher wages, workers need to exert more effort. In order to induce higher effort, employers must increase their investment in monitoring, and the result is higher productivity.

Thus, the model we have shows how the increased pressure from an alternative sector (in our case - the “self employed” sector) induces increased productivity in the “corporate sector”. Clearly, one may think of other sources of pressure that may trigger the same effect. Competition from other countries generated by trade-liberalization can clearly be one such factor (see e.g. Schmitz [2001]).

Our use of the double moral hazard as a device to create transaction costs is certainly not the only way to create an “organizational” link between growth and TFP. For example, in a standard moral hazard problem with risk-averse workers, firms would in general be forced to pay a risk premium, thereby creating a benefit to monitoring. Again, as the economy moves along a growth path, marginal benefits are likely to be affected, and optimal contracts would change. Whether this would lead to a co-movement between growth and productivity is an open question. A similar argument could be made in a model with heterogeneous workers in the presence of adverse selection, or by introducing multi-tasking. More generally, in any environment with transaction costs, the optimal organizational form is likely to be affected by growth, and in turn, affect productivity. Thus, there seems to be a wide scope of interaction between an economy’s organization, its growth and its productivity, that needs to be further explored.

References

Acemoglu, D. and F. Zilibotti, 2001: "Productivity Differences", *Quarterly Journal of Economics*, 115(3), pp.563-606.

Bernanke B. S. and R. S. Gürkaynak, 2001 : "Is Growth Exogenous? Taking Mankiw, Romer, and Weil Seriously", *NBER Macroeconomics Annual 2001.*

Demougin, D. and C. Fluet, 1998: "Mechanism Sufficient Statistic in the Risk-Neutral Agency Problem", *Journal of Institutional and Theoretical Economics*, 154(4), pp. 622-639.

Demougin, D. and C. Fluet, 2001: "Monitoring versus Incentives", *European Economic Review*, 45, pp. 1741-1764.

Hall, Robert E. and Charles I. Jones, 1999: "Why Do Some Countries Produce So Much More Output per Worker Than Others?", *The Quarterly Journal of Economics*, pp.83-116.

Jones, C. I., 1998: *Introduction to Economic Growth*, W. W. Norton and Company.

Kim, S. K., 1995: "Efficiency of an Information System in an Agency Problem", *Econometrica*, 63, pp. 89-102.

Kocherlakota, N. R., 2001: "Building Blocks for Barriers to Riches", Federal Reserve Bank of Minneapolis, Research Department Staff Report 288.

Milgrom, P. 1981: "Good News and Bad News: Representation Theorems and Applications", *Bell Journal of Economics*, 12, pp. 380-391.

Parente, S. L. and E. C. Prescott, 1999: "Monopoly Rights: A Barrier to Riches", *The American Economic Review*, 89(3), pp. 1216-1233.

Park, E. S., 1995: "Incentive Constraints Under Limited Liability", *Journal of Economics and Management Strategy*, 4, pp. 477-490.

Prescott, E. C., 1998: "Needed: A Theory of Total Factor Productivity", *International Economic Review*, 39(3), pp. 525-551.

Radner, R., 1992: "Hierarchy: The Economics of Managing", *Journal of Economic Literature*, pp 1382-1415.

Schmitz, J. A., Jr., 2001: "What Determines Labor Productivity? Lessons from the Dramatic Recovery of the U.S. and Canadian Iron-ore Industries", Federal Reserve Bank of Minneapolis, Research Department Staff Report 286.

Shi, S. , 1998: "Search for a Monetary Propagation Mechanism", *Journal of Economic Theory*, 81, pp. 314-352.