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Innovation and Growth under Private Information[1]

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Abstract

We study endogenous growth within a model with occupational choice in which innovators produce ideas, within an asymmetric information framework. Each innovator has private knowledge of their production costs. Developers offer innovators non-linear contract schemes that affect both the number of innovators and the rate of economic growth. Two main results are obtained. First, the equilibrium contract under asymmetric information leads to the selection of highly-talented workers in R&D activities. Second, the growth rate is lower in the private information case when compared to the full-information benchmark due to the existence of an efficiency-rent extraction trade-off.

Keywords: Adverse selection; Innovation; Endogenous growth.

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1. Introduction

Over the last two decades the idea that growth and the long run economic performance of firms and industries depend importantly on their ability to exploit technological innovation has gained acceptance among economists and policy makers (Aguion et al., 2005; Cohen, 2010). This has awakened a significant interest among policy makers in how policy should be designed to support innovation and encourage innovative firms to grow.

In order to be effective, policy design must consider several outcomes encountered by economic research on innovation. Among the most important findings of this literature is the fact that the distribution of firm performance is highly skewed. A small percentage of firms generate a considerable amount of innovation and employment growth. For instance, Storey (1994) showed that less than 5% of firms generate 50% of new jobs in the UK, while Cowling et al. (2004) showed that only 30% of firms create any jobs at all. Other studies show that only a small number of firms get involved in highly innovative activities. However, studying these firms is crucial as highly innovative firms are also high growth firms, in terms of the magnitude of their output, employment and productivity (Coad et al., 2014).

At first glance highly innovative firms are not easily distinguishable from less innovative ones using traditional demographic measures. However, using less traditional metrics important differences between these two types of firms arise. In particular, highly innovative firms have a significantly higher share of employment accounted for by science and engineering graduates, and this has a positive impact of different measures of firm performance. Firms with a larger share of science and engineering graduates in their total workforce are associated with more R&D, more new to market products and higher productivity growth (Coad, 2009).

Firms involved in innovative activities face several considerable challenges. One of their main challenges consists in having capable employees. These firms require talented human capital to survive and grow in highly competitive markets. But recruiting and retaining productive employees is not an easy task. In fact, Brown and Petersen (2011) show that these firms invest a high percentage of their R&D budget in hiring and retaining human capital.

Studying the process of hiring and retaining human capital in highly technological firms is very relevant. In fact, leaders of highly innovative companies work hard to instill “innovation is everyone’s job” as a guiding organizational mission. Selecting the adequate employees may boost the firm’s productivity, having a positive impact on the rate of economic growth, as we show in our theoretical model.

One way to study the selection and hiring process of talented human capital from a theoretical point of view is in a framework of the relationship between developers and innovators.

Within this framework important difficulties arise both in the process of hiring innovators and retaining them in the firm. On the one hand, innovators have private knowledge of their ideas, productivity and effort level, and developers encounter difficulties in distinguishing between promising and dull innovators. This fact creates inefficiencies that translate into agency costs both for developers and innovators in the hiring process. On the other hand, inventors with higher mobility are, on average, more productive (Hoisl, 2007). This fact implies that high turnover rates imply costs to individual firms but is beneficial for innovative industries.

Several interesting questions arise, relating to the design of contracts between developers and innovators under asymmetric information and to the macroeconomic implications of micro-distortions generated by agency problems in the R&D process.

Standard endogenous growth models explain the long-term dynamics of productivity through R&D investing (Shell, 1966; Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992). However, the literature on the impact of agency problems on knowledge production at the macroeconomic level is still scarce. This paper contributes to this literature by addressing the following questions: What is the impact of adverse selection on innovation and economic growth? How does unobserved heterogeneity in innovators' productivity affect the allocation of R&D resources? We build on the work of Martimort et al. (2010), analyzing the implications of adverse selection on R&D incentives in the bilateral relationship between developers and innovators when there is knowledge accumulation. The main benefit of introducing knowledge accumulation is that it allows us to study its impact on economic growth. Moreover, our paper deepens the understanding of the impact of "talent wars", where several developers contribute to the production of knowledge.

We extend earlier research by introducing a simple form of adverse selection into a standard endogenous growth framework. Several features distinguish our model. First, we introduce adverse selection as a component of the innovation process in order to explain growth. Second, our framework makes it possible to analyze the general equilibrium effects that adverse selection has on economic growth and resource allocation. Third, we investigate the implementation of the constrained efficient allocation through taxes and subsidies. Fourth, we study the optimal contract when there is competition between developers. This case is especially relevant in the analysis of a "talent war" between developers.

Two main results are obtained. First, the equilibrium contract under asymmetric information leads to the selection of highly-talented workers in R&D activities. Second, the efficiency-rent extraction tradeoff lowers the economic growth rate with respect to the full information case.

Section 2 presents a brief review of related literature. Section 3 presents the basic model. Section 4 characterizes the first-best allocations. Section 5 characterizes the market allocations and equilibrium prices. In Section 6, we study the model within an asymmetric information framework. The last section offers some conclusions.

2. Brief Literature Review

This paper is closely related to two strands of the literature on R&D. Namely, the literature on endogenous growth and the literature on innovation incentives under asymmetric information. A key contribution of this paper is to unify these two strands into a model capable of incorporating the microeconomic theory on innovation incentives into a macroeconomic setup.

We begin by briefly reviewing some of the most relevant studies of the impact of R&D incentives on growth. The seminal papers by Shell (1966), Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992) focus on the relation between incentives to innovate and economic growth. These incentives to innovate are characterized by monopoly rents (through patents) and investment of resources in R&D. This literature shows that when knowledge accumulates, there are spillover effects on economic activities. In particular, property rights that protect innovators lead to welfare distortions (i.e. monopoly and knowledge externalities.)

Our model differs from the standard endogenous growth model because it includes occupational choice. In our model, the allocation of labor between R&D and final production is endogenous and is distorted by adverse selection. This result is consistent with the findings of Murphy et al. (1991), in which the misallocation of talent generates a rent-seeking behavior which has a negative impact on economic growth.

A second branch of the literature deals with R&D incentives from the perspective of industrial organization and incentive theory. Using incomplete contracts, Aghion and Tirole (1994a,b) study the impact of different organizational structures on research activities. They find that the structure of an organization depends on how its innovation units are financed. This result explains the role of joint ventures in the development of R&D, as well as the role of the governments in subsidizing R&D.

As it is usually assumed in models incorporating informational asymmetries, we assume that contracts are fully enforced. Instead of studying R&D financing problems, we focus on how innovation risk provides an incentive for developers and innovators to put effort and knowledge into R&D activities.

Anton and Yao (2004) explain the failure to protect intellectual property as a problem of information disclosure that is related to the size of the innovation. The size of the innovation is measured as the change between pre- and post-innovation market shares. They find that large innovations are protected by trade secrecy. In the case of medium-sized innovations, property rights are established through licenses and patents. However, the elevated costs of full protection fail to protect small-sized innovations, allowing for imitation. In contrast, in this paper we study the potential impact of adverse selection when innovators have private information about their productivity and the size of the innovation is endogenous due to the effort undertaken by of innovators.

Martimort et al. (2010) analyze the innovation process in terms of a bilateral relationship between developers and innovators. Developers face problems of adverse selection, seeing that innovators have private information about the quality of their projects and developers must learn about the quality of the innovator's idea. The authors find that the optimal contract is one in which the innovator holds a significant share of equity in the project and in which the innovator's compensation package provides a signal on the quality of the innovation. For instance, the innovator is more likely to accept compensations with a higher variable component when they perceive that the quality of their idea is high. Incentives for innovators can be a problem because there are lower incentives for the provision of effort in R&D activities, as their ideas may be stolen by other developers.

Our paper builds on the work of Martimort et al. (2010), analyzing the implications of adverse selection on R&D incentives in the bilateral relationship between developers and innovators when there is knowledge accumulation. The main benefit of introducing knowledge accumulation is that it allows us to study its impact on economic growth. Moreover, our paper deepens the understanding of the impact of "talent wars", where several developers contribute to the production of knowledge

3. The Model

Our endogenous growth model builds on Aghion and Howitt (1992), with two main differences: innovators' productivity is heterogeneous, and productivity is privately observed by innovators.

The economy is composed by three types of agents: individuals, a final goods producer and a developer. There is a continuum of individuals with identical preferences and different productivity levels, θ. We assume $\theta \sim [0,1]$ with cdf $F(\theta)$. The types θ are i.i.d. over time. Individuals can provide one unit of labor either to the final goods sector or the R&D sector. If the individual chooses to be a worker (W) and offers their labour to the final goods sector, they will provide one unit of labor and zero effort and will receive a wage w per period. On the contrary, the individual who chooses to be an innovator (I) will offer their labor to the R&D sector and provides a positive amount of effort e (endogenously determined), receiving a compensation τ. In both cases preferences are represented by the following utility function:

$$U = E_0 \int_0^{\infty} ln\left(c_t^j - \frac{e_t^2}{2}\right) exp(-\rho t)dt \qquad (1)$$

where c_t^j is the consumption of the individual depending on the occupational choice $j = W, I;\ \rho > 0$ is the discount rate. These preferences are a particular case of GHH preferences in which there are no income effects on the labor supply. Hence, intertemporal substitution for consumption is independent of effort.

Final good Y_t is produced by the final goods sector. It is worth both for consumption and as an input for the R&D sector. Total final output is a combination of labor in the final good sector, L^Y, and a continuum of intermediate goods x_i:

$$Y_t = (L^Y)^{1-\alpha} \int_0^1 A_{i,t}^{1-\alpha} x_{i,t}^{\alpha}\, di \qquad (2)$$

where $A_{i,t}$ is the level of knowledge used in sector i at time t. The price of the final good is the numeraire and production occurs in a competitive market.

There is a continuum of intermediate sectors. In each sector i there is a representative developer who is in charge of the production of intermediate goods. At each date t, each intermediate good is produced according to the linear technology function $x_{i,t} = y_{i,t}$, where $y_{i,t}$ is the quantity of the final output used to produce $x_{i,t}$.

At time t, each sector is characterized by $A_{i,t}$ and the total stock of knowledge is aggregated across sectors: $A_t = \int_0^1 A_{i,t} di$. The R&D activity in each sector satisfies three assumptions:

1. In sector i, R&D activity produces blueprints q_i that are a combination of the effort exerted by the individual e and their ability θ:

$$q(\theta) = \theta + \frac{e(\theta)}{\sqrt{A_t}} \qquad (3)$$

Note that the total production of blueprints in the economy is given by $q = \int_i \; q_i d_i$. Both the effort exerted by the innovator and his ability are substitutes in the production of blueprints. Hence, a not very talented innovator can produce blueprints is a great effort in started in productions. Conversely, a very talented innovator needs a small effort in order to produce them. Equation (3) can be also interpreted as the probability of producing a new blueprint by an innovator of ability θ who makes an effort e (see, for instance, Holstrom, 1999; and, Martimort et al., 2010). This assumption is quite standard in the theory of incentives literature (Laffont and Tirole, 1993). Results remain unchanged if complementarity between ability and effort is assumed, as in Aghion and Tirole (1994a,b).

Total production is given by the aggregation of θ above a productivity threshold $\hat{\theta}$ which is subsequently determined: $q_i = \int_{\hat{\theta}_i}^1 q(\theta) dF(\theta)$.

2. Innovations follow at a Poisson rate $\lambda > 0$. Since there is a continuum of independent R&D sectors, the innovation rate is equal to λq_i.
3. Variations in the stock of knowledge are given by $\Delta A_{i,t} = \sigma A_t$, where $\sigma > 1$ is the frequency of innovation. Innovation leads to a change in the knowledge stock in sector i that is proportional to the whole disposable knowledge in the economy. The law of motion for average knowledge in the economy is given by:

$$A_{i,t+\Delta t} \approx \left(A_{i,t} + \sigma A_t\right)\lambda q_{i,t}\Delta t + A_{i,t}\left(1 - \lambda q_{i,t}\Delta t\right) \qquad (4)$$

$$A_{i,t+\Delta t} = A_{i,t} + \sigma\, \lambda q_{i,t} A \Delta t$$

The final assumption implies that instantaneous changes in the stock of knowledge are equal to:

$$lim_{\Delta t \to 0} \frac{A_i(t+\Delta t) - A_i(t)}{\Delta t} = lim_{\Delta t \to 0} \frac{\sigma \lambda q_{i,t} A \Delta t}{\Delta t} \qquad (5)$$

Moreover, the expected change in the stock of knowledge in each sector is given by:

$$\dot{A_{\iota,t}} = \sigma A_t\, \lambda q_{i,t} \qquad (6)$$

We now characterize the full information case, the first-best and the equilibrium outcomes. Then we study the role of informational frictions, specifically the constrained efficient allocation and equilibrium contracts under adverse selection.

Similar dynamics for the stock of knowledge are assumed by several papers in the related literature. See, for instance, Jones (1999).

4. First Best Allocations

Consider a central planner who observes innovator's ability θ and makes decisions about consumption, R&D effort, intermediate goods, labor in the final goods sector and R&D investment. This central planner solves the following problem:

$$max_{\{c_t^w, c_t^I, q_t, \hat{\theta}^{fb}, x_{i,t}, A_{i,t}\}} \int_0^\infty \left[\int_0^{\hat{\theta}^{fb}} ln\left(c_t^w(\theta)\right)dF(\theta) + \int_{\hat{\theta}^{fb}}^1 ln\left(c_t^I(\theta) - A_t\left(\frac{(q_t-\theta)^2}{2}\right)\right)dF(\theta)\right] exp(-\rho t)dt \qquad (7)$$

subject to (2), (6) and $Y_t = \int_0^{\hat{\theta}^{fb}} c^w(\theta)dF(\theta) + \int_{\hat{\theta}^{fb}}^1 c^I(\theta)dF(\theta) + \int_0^1 x_{i,t}di$

The central planner maximizes social welfare by maximizing utility across individuals with ability θ. Social weights are determined by occupational choices $\hat{\theta}^{fb}$. First order conditions (FOC) are:

$$[c_t^W, c_t^I] : \quad \frac{exp(-\rho t)}{c_t^W} = \frac{exp(-\rho t)}{c_t^I - A_t \frac{e_t^2}{2}} = \mu \qquad (8)$$

$$[q_t] : \quad \frac{(q_t - \theta) exp(-\rho t)}{c_t^I - A_t \frac{e_t^2}{2}} = \lambda\sigma \int_0^1 \eta(i) di \qquad (9)$$

$$[A_t] : \; -\int_{\hat{\theta}^{fb}}^1 \frac{\frac{e_t^2(\theta)}{2}}{c_t^I - A_t \frac{e_t^2}{2}} dF(\theta) exp(-\rho t) + \mu \left[(1-\alpha)(L^Y)^{1-\alpha} \int_0^1 A_{i,t}^{-\alpha} x_{i,t}^{\alpha}\right] + \lambda\sigma \int_0^1 \eta(i) di \int_{\hat{\theta}^{fb}}^1 q_t dF(\theta) = -\dot{\eta} \qquad (10)$$

$$[\hat{\theta}^{fb}] : \quad \mu\left[(1-\alpha)\frac{Y_t}{\hat{\theta}^{fb}}\right] = \lambda\sigma\left(e_t + \hat{\theta}^{fb}\right) \int_0^1 \eta(i)\, A_{i,t} di \qquad (11)$$

$$[x_{i,t}] : \quad \mu\left[\alpha (L^Y)^{1-\alpha} \int_0^1 A_{i,t}^{1-\alpha} x_{i,t}^{\alpha-1} - 1\right] \qquad (12)$$

In equation (8), μ stands for the Lagrange multiplier associated with the aggregate resource constraint. From the FOC, $c_t^W = c_t^I - \frac{A_t e_t^2}{2}$. This means that the central planner chooses allocations in such a way that the difference between the consumption of innovators and workers is equal to the amount of R&D effort.

Equation (9) tells us that the marginal value of R&D effort must be equal to the marginal value of R&D investment, where $\int_0^1 \eta(i)$ is the sequence of Lagrange multipliers associated to the law of motion of knowledge.

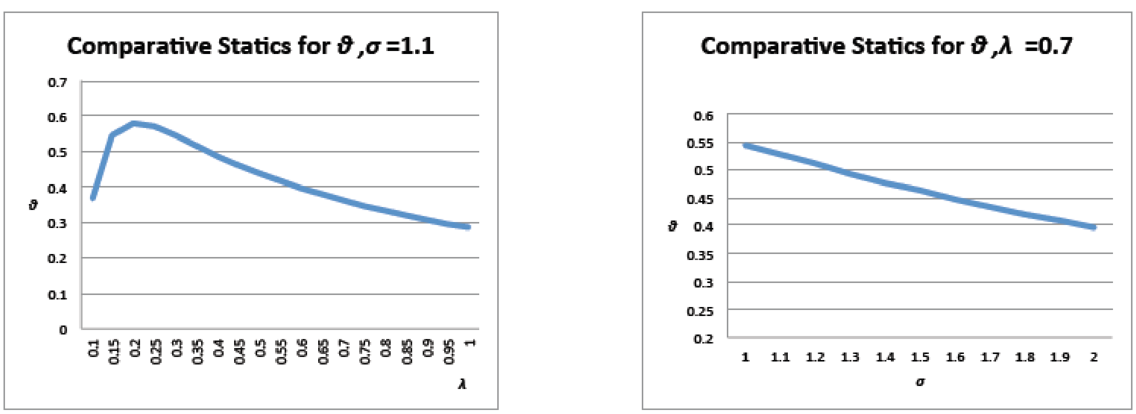
Equation (10) implies that the marginal value of a unit of knowledge is equal to the disutility of providing effort in R&D activities plus the marginal productivity of knowledge and the marginal value of R&D investment. Finally, equations (11) and (12) describe, respectively, standard demand for labor in the final goods sector and demand for intermediate goods.

Proposition 1 At the symmetric steady-state first-best, the central planner's allocations are: $Y^{fb} = \hat{\theta}^{fb} A\alpha^{\alpha/(1-\alpha)}$, $x^{fb} = \hat{\theta}^{fb} A\alpha^{\alpha/(1-\alpha)}$, $c^{fb} = \hat{\theta}^{fb} A\alpha^{\alpha/(1-\alpha)}(1-\alpha^{\alpha})$, $q^{fb} = \frac{\left(\sqrt{\hat{\theta}^{fb^2} + 4(1-\alpha)\alpha^{\frac{\alpha}{(1-\alpha)}}} - \hat{\theta}^{fb}\right)}{2} + \theta$. The steady-state growth rate is $g_Y^{fb} = g_X^{fb} = g_c^{fb} = g^{fb} = \sigma\lambda \frac{(1-\hat{\theta}^{fb})}{2}\left[\sqrt{1 + \hat{\theta}^{fb^2} + 4(1-\alpha)\alpha^{\frac{\alpha}{(1-\alpha)}}}\right]$, and for $\hat{\theta}^{fb} \epsilon [0,1]$ there is a unique productivity threshold $\hat{\theta}^{fb}$.

According to Proposition 1, in the first-best the allocations of output, intermediate goods and aggregate consumption are proportional to the stock of knowledge and the productivity threshold. Second, the optimal growth rate depends positively on the total amount of labor allocated to R&D and on the parameters related to the intensity of knowledge spillovers, λ and σ. The parameter λ indicated the contribution that blueprint production exerts on the stock of knowledge. The parameter σ represents the influence of the total stock of knowledge on the quality of improvements made in each sector.

Based upon a set of reasonable parameter values for the final output (namely $\alpha\epsilon(0{,}1)$, $\lambda\epsilon(0{,}1)$ and $\sigma > 1$, there is a unique productivity threshold $\hat{\theta}^{fb}$. Figure 1 illustrates, using numerical examples, the sensitivity of the productivity threshold to the values of the technological parameters. The first panel shows how $\hat{\theta}^{fb}$ changes as blueprint production become more efficient (R&D labor increases when blueprints are more efficiently produced). The same effect occurs when the influence of the total stock of knowledge on the production of innovations increases (second panel.)

Figure 1: Sensitivity of $\hat{\theta}^{fb}$ to λ and σ



5. Decentralized Allocations

In this section we describe the market allocations.

5.1 Timing

In each time period t, the production process consists of the following stages:

Stage 1: Each individual learns their type.

Stage 2: The R&D sector proposes a contract that specifies the amount of blueprints in each sector and the income perceived by innovators.

Stage 3: The final goods sector proposes a contract that specifies the labor and wage that workers will receive.

Stage 4: Each individual, by choosing to be a worker or innovator, accepts one of the contracts and rejects the other.

Stage 5: Each innovator chooses an effort level.

Stage 6: Intermediate goods are produced and priced by the developer and sold to price-taking firms in the final goods sector.

Stage 7: Competitive firms in the final goods sector use intermediate goods as inputs for final output production.

Stage 8: Individuals are paid and choose their consumption and saving profiles.

5.2 Individuals' Occupational Choices

Let $\nu = max\{\upsilon_w, \upsilon_I\}$, where υ_w and υ_I are, respectively, the value functions when the individual becomes an innovator and when they become a worker, respectively. If these value functions exist, then there is a productivity threshold $\hat{\theta}$ that determines the allocation of labor. Specifically:

If $\theta = \hat{\theta}$, the individual is indifferent between becoming an innovator or a worker in the final goods production. This is the case if $\upsilon_w(w) = \upsilon_I\left(\theta, e^D(\theta)\right)$. If $\theta < \hat{\theta}$, the individual prefers to be an innovator. This is the case if $\upsilon_w(w) < \upsilon_I\left(\theta, e^D(\theta)\right)$. If $\theta > \hat{\theta}$, the individual prefers to work in the final goods sector. This is the case if $\upsilon_w(w) > \upsilon_I\left(\theta, e^D(\theta)\right)$.

The value function results from solving the following problem:

$$max_{c_t^j, b_{t+1}^j} \int_0^\infty \left(ln\left(c_t^j - \frac{e_t^2}{2}\right) exp(-\rho t)\right) dt \qquad (13)$$

subject to

$$c_t^j + \dot{b}^j = \zeta_t + r_t b^j$$

and equation (3), with b_0 given.

The objective of the individual is to choose consumption c_t^j and assets b_t^j for each occupation, in order to maximize the present discounted value of utility. At this stage, effort is taken as given. The optimal level of effort will be determined in the R&D market. The total revenue of each individual (i.e. total income that depends on occupational choice and asset earnings) is used to purchase consumer goods and assets. The standard Euler condition implies that the marginal rate of substitution is constant over time and equal to the interest rate:

$$g_{\tilde{c}^j} = r_t - \rho \qquad (14)$$

where $\tilde{c}^j = c_t^j - \frac{e_t^2}{2}$, and $g_{\tilde{c}^j}$ is the growth rate of $\tilde{c}^j$. Since preferences have no income effect, the level of effort is determined by reward for R&D activities, i.e. ζ. By using the guess and verify method, we can obtain the policy function for each occupational choice:

$$c^I = \frac{e^2}{2} + \rho b^I \qquad (15)$$

and

$$c^w = \rho b^w \qquad (16)$$

The corresponding value functions are:

$$v_I = \zeta - \frac{e^2}{2} + \frac{1}{\rho} ln b^I \qquad (17)$$

and

$$v_w = w + \frac{1}{\rho} ln b^w \qquad (18)$$

5.3 Final Good Producers

Competitive firms purchase intermediate goods and use them to produce final homogeneous goods according to the existing technology. We use the price of final goods as numeraire. Let x be the amount of intermediate goods that is bought by the firm and let p be the price per unit of intermediate good. Producers of final goods solve the following problem in each time period:

$$max_{\{x_{i,t}, L_t^Y\}} B_t = (L^Y)^{1-\alpha} \int_0^1 \left(A_{i,t}^{1-\alpha} x_{i,t}^{\alpha} - x_{i,t} p_{i,t}\right) di - w_t L_t^Y \qquad (19)$$

The FOC with respect to intermediate goods is:

$$x_{i,t} = \left(\frac{\alpha}{p_{i,t}}\right)^{\frac{1}{1-\alpha}} A_{i,t} L^Y \qquad (20)$$

Hence, the demand for intermediate goods depends positively on sectorial productivity and negatively on the price of intermediate goods. The demand for labor for the production of final goods is given by:

$$(1-\alpha)\frac{Y_{i,t}}{L} = w_t \qquad (21)$$

5.4 Innovation and Development

Each sector is characterized by a developer in charge of producing intermediate goods. When an innovation occurs, the corresponding developer obtains a life-lasting patent on their innovation. Hence, the developer obtains a monopolistic profit by selling their intermediate good to the producer of final goods. Sector $i's$ developer chooses the price that maximizes their profit. They solve the following problem:

$$max_{p_{i,t}} \pi_{i,t} = p_{i,t} x_{i,t} - y_{i,t} \qquad (22)$$

subject to equation (20) and $x_{i,t} = y_{i,t}$. The corresponding FOC is given by:

$$p_i = \frac{1}{\alpha}, \quad \forall \qquad (23)$$

Monopolistic pricing entails a mark-up, $\frac{1}{\alpha}$. Given the mark-up is equal for all goods produced in sector i, the demand for each intermediate good is given by:

$$x_{i,t} = \alpha^{2/(1-\alpha)} A_{i,t} L^Y \qquad (24)$$

Therefore, each monopolist in sector i perceives a profit equivalent to:

$$\pi_{i,t} = \tilde{\pi} A_{i,t} L^Y \qquad (25)$$

where $\tilde{\pi} = (1-\alpha)\alpha^{(1+\alpha)/(1-\alpha)}$ corresponds to the market-power factor. In words, profit in each sector is proportional to effective labor, $A_{i,t}L^Y$, and depends on the market-power factor. Improvements in technology increase the developer's profit from selling intermediate goods. This, in turn, increases the demand for labor in the final goods sector.

5.5 R&D Activity

The developer invests in R&D and innovates with probability λq_t. In the event of success the outcome is a new version of the intermediate good. In that case, the developer obtains a monopolistic rent obtained from a patent with mean duration $\frac{1}{\beta}$.

Total investment in R&D corresponds to the aggregation of payments made to individual innovators. A contract in R&D activity corresponds to a duple of outcome and payoff $\{q(\theta), \zeta(\theta)\}$ offered by the developer to the innovator. The innovator can sign just one contract. Hence, his innovation will serve just one sector. In this study we consider the case of short-term contracts, replicating the high turnover rate observed in highly innovative industries.

The developer solves the following problem:

$$max_{q(\theta),\zeta(\theta)} \lambda q_t(\theta) V_t - \zeta(\theta) \qquad (26)$$

subject to (3) and the participation constraint:

$$\zeta(\theta) - \frac{e^2(\theta)}{2} + \frac{1}{\rho} lnb^I(\theta) \geq w + \frac{1}{\rho} lnb^w \qquad (27)$$

where $\zeta(\theta)$ is the total reward for innovator type θ.

At the optimum the participation constraint is binding. Hence, the FOC is the following:

$$V_t = \frac{q_t - \theta_t}{\lambda} A_t \qquad (28)$$

This FOC implies that the benefit gained from investing q_t in final output is optimally equal to the level of R&D effort.

5.6 Capital Markets

R&D activity is financed by the issuance of equity claims on the profits generated by the innovation activity:

$$V_t = \int_t^{\infty} \pi_s \, exp\left(- \int_t^s (r(u) + \beta) ds\right) ds \qquad (29)$$

Therefore, in the time interval dt, a developer receives profits equivalent to $\pi_i dt$, and the value of the firm in sector i increases in the amount $\dot{V}_i dt$. Since quality improves every time a new innovation is produced, shareholders suffer a loss equivalent to V_i for every innovation. This event occurs with probability β. Consequently, the developer receives zero profit and is replaced by another developer using a more efficient technology.

We are assuming efficient capital markets. Hence, the expected rate of return of holding a stock in R&D activity must equal the risk-free rate obtainable in a competitive market, $rd(t)$. The arbitrage-free condition in this market yields:

$$r(t) + \beta = g_v + \frac{\pi_t}{V_t} \qquad (30)$$

where g_v is a measure of capital gains obtained by shareholders. Since the interest rate is endogenous, the arbitrage-free condition is given by $g_c + \rho + \beta = g_v + \frac{\pi_t}{V_t}$.

5.7 Definition of a Symmetric Equilibrium

An equilibrium for this economy consists of a collection of sequences $\{c_t^W(\theta), c_t^I(\theta), e_t(\theta), x_t(\theta), L_t^Y(\theta)\}_{t=0}^{\infty}$, $\forall\theta\epsilon\Theta$, a path for the state variable $\{A_t\}_{t=0}^{\infty}$, and a sequence of prices $\{w_t, p_t\}_{t=0}^{\infty}$ and $\{\zeta_t(\theta)\}_{t=0}^{\infty}$ for all $\theta\epsilon\Theta$ such that:

$\{w_t\}_{t=0}^{\infty}$, $\{c_t^W(\theta)\}_{t=0}^{\infty}$ for all $\theta\epsilon\Theta$, solve the individual's problem of being a worker.

$\{\zeta_t(\theta)\}_{t=0}^{\infty}$, $\{c_t^I(\theta), e_t(\theta)\}_{t=0}^{\infty}$ for all $\theta\epsilon\Theta$, solve the problem of being an innovator.

$\{w_t, p_t\}_{t=0}^{\infty}$, $\{x_t(\theta)\}_{t=0}^{\infty}$ for all $\theta\epsilon\Theta$, solve the problem of the final sector.

$\{A_t\}_{t=0}^{\infty}$, $\{p_t\}_{t=0}^{\infty}$, $\{\zeta_t(\theta)\}_{t=0}^{\infty}$, $\{e_t(\theta)\}_{t=0}^{\infty}$ for all $\theta\epsilon\Theta$, solve the developer's problem.

And markets clear at every t:

$$L^Y = F(\hat{\theta})$$

$$1- \ F(\hat{\theta}) = e(\hat{\theta})$$

$$\int_0^{\hat{\theta}} b_t^W(\theta)dF(\theta) + \int_{\hat{\theta}}^1 b_t^I(\theta)dF(\theta) = 0$$

$$Y_t = \int_0^{\hat{\theta}} c_t^W(\theta)dF(\theta) + \int_{\hat{\theta}}^1 c_t^I(\theta)dF(\theta) + \int_0^1 x_{i,t}\,di \qquad (31)$$

5.8 Characterization of the Steady-State Symmetric Equilibrium

In this subsection, we characterize the symmetric steady-state equilibrium allocations. Proposition 2 examines the balanced growth path of the model and the productivity threshold that arises at the equilibrium.

Proposition 2 In the full-information case, and assuming a uniform distribution of types θ, there is a unique balanced growth path characterized by a symmetric equilibrium: $Y_t^* = \alpha^{\frac{2\alpha}{1-\alpha}}\hat{\theta}A_t,\ q^* = \frac{\tilde{\pi}\lambda\hat{\theta}}{\rho+\beta} + \theta,\ x_t^* = \alpha^{\frac{2}{1-\alpha}}\hat{\theta}A_t,\ r_t = \rho + g^*,\ w_t = (1-\alpha)\alpha^{\frac{2}{1-\alpha}}A_t,\ p = \frac{1}{\alpha},\ g^* = (1-\hat{\theta})\left[\hat{\theta}\left(\frac{\sigma\lambda^2\tilde{\pi}+\rho+\beta}{2(\rho+\beta)} + \frac{1}{2}\right)\right],\ \hat{\theta} = \sqrt{\frac{2(\rho+\beta)}{\lambda\alpha(\tilde{\pi}\lambda+1)}} > 0.$

This economy's growth rate, g^*, is determined by the proportion of monopoly developer rents, adjusted for the rate of creative destruction and the mean value of the skill of its workers. As it is often the case in Schumpeterian models, there is a scale effect due to R&D labor. In this context, increases in R&D investment have two effects. First, increased blueprint production has a positive effect on growth, which means more monopolistic rents and therefore higher revenue for the developer. Second, greater investment in R&D implies a higher selection of labor (a higher threshold $\hat{\theta}$), which reduces blueprint production. The trade-off between these two opposite effects determines the optimal amount of R&D effort in the economy.

Developers offer non-linear transfers to agents in such a way that they are competitive with respect to the final goods sector and determine the equilibrium productivity level. The productivity cut-off is determined in equilibrium. It corresponds to the level of productivity at which the worker is indifferent between offering their labor to the production of final sector goods or to the production of innovation.

The developer must offer contracts that are at least as good as the wage offered by the final goods sector. At the equilibrium, the productivity threshold positively depends on both the mark-up and the rate of creative destruction. In both cases, the effect is positive but decreasing. The explanation for this result is rather straightforward: as the economy grows, demand for intermediate goods increases. Therefore, more labor is allocated to the final goods sector. And, depending on the probability that the replacement technology will be adopted, the higher the quality of the innovation, the higher the number of workers that will choose to work in the final goods sector.

6. Informational Asymmetries

This section describes the allocations when a central planner faces informational constraints about the skill levels in the production of blueprint technology. We then study this problem in a decentralized economy. We characterize the optimal contract between the developer and the innovators and explain the main distortions that arise with respect to the constrained efficient outcome.

6.1 Constrained Efficient Allocation

Let us assume that the innovator has private information about their productivity, and is required to fill a report. Contingent on this productivity report, the allocation is given by $Z(\theta) \equiv \{c_t(\theta), c_t(\theta), q_t(\theta), e_t(\theta)\}_{t=1}^{\infty}$ for all $\theta \epsilon \Theta$, for each time period t .

Assuming that the central planner implements a direct mechanism, a productivity report $\tilde{\theta}$ is requested and an allocation $Z(\tilde{\theta})$, is delivered in exchange. In order to encourage truthful reporting, we require that $Z(\tilde{\theta}) = Z(\theta)$. Specifically, the optimal allocation must satisfy the following incentive compatibility constraint (ICC):

$$\int_0^{\infty} In\ (c_t^I(\theta) - A_t((q_t(\theta) - \theta)^2/2\ ))\ \exp(-\rho t)]dt \geq$$

(32)

$$\int_0^{I} In(c_t^I(\theta') - A_t((q_t(\theta') - \theta)^2/2))\ \exp(-\rho t)]dt$$

The ICC in equation (32) represents the lifetime discounted utility of an agent who reports the true productivity type θ and works for an R&D sector where productivity is higher than any other $'$. We apply the following transformation $\tilde{u}_t^I(\theta) = c_t^I(\theta) - A_t((q_t(\theta) - \theta)^2\ /2)$ and define $\varphi(\theta) = \int_t^{\infty} \tilde{u}_t^I(\theta)\ \exp(-\rho t)]dt$. This transformation preserves the typo ranking.

The ICC has two components: the informational rent and the monotonicity (effort) constraints. The informational rent means that the central planner delivers the agent a level of utility of at least their discounted reservation utility. In other words, the agent receives the discounted utility perceived by the worker in the final goods sector plus a reward. This reward is proportional to the total effort that the agent exerts when working in R&D activities.

$$\varphi(\theta) = \varphi(\theta, \theta') + \underbrace{\int_t^{\infty} \int_{\tilde{\theta}}^{\theta} (A_{t(q(x)-x)})}_{\text{Information rent}}\ dx\ \exp(-\rho t)dt \tag{33}$$

The monotonicity constraint means that the central planner offers reward schemes that are based on increasing effort; i.e. the production of blueprints decreases with respect to productivity θ.

$$\int_t^{\infty} \left(\frac{dq_t}{d\theta}(\theta)\right) \exp(-\rho t) \leq 0 \tag{34}$$

We find the optimal solution of the relaxed program, i.e. a solution for the optimization program that takes into account informational rents. We then verify that the monotonicity condition is actually satisfied. The central planner solves the following problem:

$$\max_{\{c_t^w, c_t^I, q_t, \theta\hat{f}b, x_{i,t}, A_{i,t}\}} \int_t^{\infty} \left[\int_0^{\theta\hat{f}b} (c_t^w(\theta))\ dF(\theta) + \int_{\theta\hat{f}b}^{1} (c_t^I(\theta) - A_t((q_t - \theta)^2 / 2))\big(1 + \Delta(\theta)\big) dF(\theta) \right] \exp(-\rho t) \tag{35}$$

Where $\Delta(\theta) = \frac{1-F(\theta)}{f(\theta)}$ is the inverse of the hazard rate, and subject to (2), (6), and (31).

This problem's FOC are:

$$[c_t^w, c_t^I]:\ \ \exp^{-\rho t} = \mu \tag{36}$$

$$[q_t]: (q_t - \theta)\big(1 + \Delta(\theta)\big) \exp^{\rho t} = \lambda\sigma \int_0^1 \eta(i)\, di \tag{37}$$

$$[A_t]: -\int_{\theta\hat{f}b}^{1} ((q-\theta)^2\ /2\,)\,(1+\Delta(\theta))\ dF(\theta)\, exp^{-\rho t} + \mu\left[(1-\alpha)(L^y)^{1-\alpha} \int_0^1 A_{i,t}^{-\alpha}\ x_{i,t}^{\alpha}\ \right] + \lambda\sigma \int_0^1 \eta(i) di\ \int_{\tilde{\theta}}^1 q_t dF(\theta) = -\dot{\eta} \tag{38}$$

$$[\theta\hat{f}b]: \left[(1-\alpha)\frac{Y}{\hat{\theta}}\right] = \lambda\sigma\left(q\big(\hat{\theta}\big)\right)\frac{\eta}{\mu}\ A + A\frac{\big(q(\hat{\theta})-\hat{\theta}\,\big)^2}{2}\ (1+\Delta(\theta)) \tag{39}$$

$$[x_t]: \qquad \mu\left[\alpha(L^y)^{1-\alpha}\int_0^1 A_{i,t}^{1-\alpha} x_{i,t}^{\alpha-1} - 1\right] \tag{40}$$

These FOC introduce two distortions. First, there is underproduction of blueprints: the left-hand side of (37) shows that informational frictions increase the marginal cost of providing effort in a magnitude equivalent to $(q_t - \theta)\Delta(\theta)$. Second, distortions in blueprints production affect investment in R&D (38) as well as the optimal occupational choice (equation (39).)

6.2 Bilateral Asymmetric Information: Developers and Innovators

The principal offers contracts $\{q_t(\theta), \tau_t(\theta)\}_{\theta\epsilon\Theta}$ that constitute a payment $\tau_t(\theta)$, in exchange for a certain number of blueprints $q_t(\theta)$. As the contractual problem is symmetric for all sectors i, we skip the index i. Consequently, under this informational constraint, each innovator θ is motivated to choose a contract $\{q_t(\theta), \tau_t(\theta)\}$ rather than $\{q(\theta'), \tau(\theta')\}$.

In this case, we assume that private information about productivity affects the distribution of the output produced by the innovator in each time period t. At it is shown in the Appendix, the production of blueprints satisfies the following monotonicity constraint:

$$\frac{dq_t}{d\theta}(\theta) \leq 0 \tag{41}$$

The problem for the developer under asymmetric information is given by:

$$\max_{q_t(\theta),\tau_t(\theta)} \int_{\hat{\theta}_\iota}^{1} [\lambda q_t(\theta)V_t - \tau(\theta)]dF(\theta)$$

subject to the participation constraint (70) and (41).

Since the Spence-Mirrlees condition is satisfied, the local incentives constraint implies the existence of global constraints. In order to solve this problem, we characterize the *relaxed problem*, in which the monotonicity constraint is initially ignored. Once the relaxed problem is solved, we can verify that the monotonicity constraint is satisfied. Using integration by parts, the developer's problem can be written as:

$$\max_{q_t(\theta),\tau_t(\theta)} \int_{\hat{\theta}_\iota}^{1} \left[\lambda q_t(\theta)V_t - A_t\left(\frac{(q_t-\theta)^2}{2} + \frac{(1-F(\theta))}{f(\theta)}(q_t-\theta)\right)\right] dF(\theta) - \varpi(1-\hat{\theta}) \quad (42)$$

subject to (70) and (41).

The FOC is:

$$[q_t]: V_t = \frac{A_t}{\lambda}\left[(q_t-\theta) + \frac{(1-F(\theta))}{f(\theta)}\right] \quad (43)$$

Equation (43) establishes the value of an innovation. This value is equal to the level of effort under asymmetric information, and it includes the trade-off between efficiency and current rent-extraction frictions. The informational friction is captured by the inverse of the hazard rate, defined by $\Delta(\theta) = \frac{1-F(\theta)}{f(\theta)}$.

Proposition 3 (Growth and Selection) Under asymmetric information, the equilibrium menu of contracts entails

- Distortion in the equilibrium quantity of blueprints: $q^{AI}(\theta) = \frac{\lambda\tilde{\pi}\hat{\theta}^{AI}}{(\rho+\beta)} + \left(\theta - \frac{(1-F(\theta))}{f(\theta)}\right) < q^*(\theta)$.
- Reduction of the economy's growth rate with respect to the full-information case: $g^{AI} = \left(1-\hat{\theta}^{AI}\right)\left[\hat{\theta}^{AI}\left(\frac{\sigma\lambda^2\,\hat{\pi}}{\rho+\beta}\right)\right] < g^*$.
- Distortion in the cut-off level of productivity: $\hat{\theta}^{AI} > \hat{\theta}$

Under asymmetric information, the value of producing one unit of blueprints is given by the level of R&D effort plus the information rent that the developer transfers to the innovator as an incentive to exert more effort. The adverse selection problem leads to a distortion in the equilibrium number of blueprints. In particular, the number of blueprints chosen by the developer affects the number of workers engaged in each activity. This is the traditional rent extraction trade-off that generates a greater level of separation across productivity levels.

There is also a selection effort. As the mean value of productivity increases, there are scaling effect that positively affect the rate of economic growth.

Table 1: Main Parameters

λ	α	ρ	σ	β	G
0.7	0.6	0.07	1.1	0.47	0.02

The additional rent that the innovator receives can be calculated as the difference between payoffs under private and full information. This is proportional to the developer's profit and to the distortion generated by asymmetric information in the labor market:

$$\Psi(\hat{\theta}) = \tau^{AI}(\theta) - \tau^{*}(\theta) = A\frac{\tilde{\pi}\lambda}{\rho+\beta}\left(\hat{\theta}^{AI} - \hat{\theta}^{*}\right) \tag{45}$$

6.3 Implementation

In this section we compute the allocations of the central planner with those of the market under different information scenarios. We consider two types of friction: externality generated by knowledge in the rest of the economy, and distortion generated by monopolistic developers in the production of intermediate goods and the private information of innovators.

We propose the following instrument: $T(q) = -t + \psi q$, which play a role in the production of blueprints. Additionally, we introduce a subsidy to the production of intermediate goods. To calculate optimal instruments, we calibrate the model according to the parameterization presented in Table 1. Parameters are calibrated following Jones (1995). We examine three information scenarios: a full-information case (Full); an asymmetric information case (AI) in which there are informational asymmetries between the central planner and agents; and a partial information case (PI), where only market agents have asymmetric information.

We first calculate productivity thresholds for the full-information case, $\theta^{\hat{f}^{b}}, \theta^{\widehat{D}}$, for both the central planner and decentralized allocations, respectively (see Table 2.) We find that at the market equilibrium, the proportion of the labor force devoted to R&D is greater that the socially efficient level. The same occurs in a comparison of constrained efficient allocations and decentralized allocations when there is asymmetric information between the developer and innovators, $\theta^{\hat{C}E}, \theta^{\hat{A}I}$.

When we calculate optimal instruments (see table 3,) we find that under asymmetric information it is optimal to subsidize the production of intermediate goods (s) and impose taxes on the production of blueprints under all information scenarios ($\psi^{Full}, \psi^{AI}, \psi^{PI}$.) These instruments enable us to correct the overinvestment in R&D problem that appears in the model.

Table 2: Productivity Thresholds

$\theta^{\hat{f}b}$	$\theta^{\hat{D}}$	$\theta^{\hat{C}E}$	$\theta^{\hat{A}I}$
0.54	0.35	0.58	0.42

Table 3: Optimal R&D Taxes/Subsidy

ψ^{Full}	ψ^{AI}	ψ^{PI}	s
0.05	0.10	0.07	-0.4

6.4 Multiple Developers

In the previous section, we described the case where a single developer operating in sector i offers a set of contracts that are incentive-compatible with the wage offered in the final goods sector. In this section, we look more closely at how internal competition in R&D activities affects the incentives to innovate under private information. In this setting, each firm in sector i competes with other R&D firms to attract talented innovators.

In this case, the participation constraint is dependent on the level of productivity θ. In this section we show that, given a productivity threshold $\hat{\theta}$, there are incentives for developers to propose alternative contracts that have the potential to be attractive to innovators. There are at least two incentives for developers to compete. The first one is to maintain a monopoly position and beat the competition. In this case, developers hire talented innovators and invest in R&D to maintain their market power. The second one is that an important contractual externality emerges from competition, which reflects developer's willingness to innovate. This point is important because demand for innovation was passive in our previous setup, as demand for new intermediate goods depended on the mark-up.

The technique applied in this subsection follows that used by Biglaiser and Mezzetti (1993), Champsaur and Rochet (1989), and Jullien (2000). In general, the problem to solve is given by:

$$\max_{q_t(\theta)U^I} \int_{\hat{\theta}_i}^{1} \{\lambda q_t(\theta)V_t - A_t[(q(\theta)-\theta)^2 /2 \ \ U^I(\theta)]\} \, dF(\theta) \tag{46}$$

Subject to [3] and

$$\frac{dU^I}{d\theta}(\theta) = (q(\theta) - \theta) \tag{47}$$

$$U^I(\theta) \geq U^0(\theta) \tag{48}$$

As before, the objective function considers innovation flows and the cost of making an effort, taking into account the monotonicity constraint and the opportunities offered by another firm in sector i. The key aspect here is that informational rents are not monotonic, and the lie within the participation constraint. When there is competition among developers, the characterization of R&D contracts is non-trivial; in fact, there is endogenous exclusion and there are also bunching regions (see Jullien (2000))

All of this matters for growth. Competition leads to change in R&D investment. From the point of view of developers, it implies more rent extraction. The next proposition concerns the configuration of cream-skimming R&D contracts in the model.

Proposition 4 (Cream-skimming contracts) Let us suppose that a firm offers a contract $o \in i \, \{\tau^o, q^o\}$. Then, a cream-skimming contract is characterized by two productivity thresholds $\{\theta_1, \theta_2\} \in \left[\hat{\theta}, 1\right]$such that:

- On $\left[\hat{\theta}, \theta_1\right]$ there is an upward distortion on which the amount of blueprints is $\bar{q}(\theta) = \frac{1}{\eta}V + \theta + \frac{1}{\eta}\left(1 - \hat{\theta}\right)$
- On $[\theta_1, 1]$ there is a bunching region and the blueprints quantities are given by $\bar{q}(\theta) = q^o = \frac{1}{\eta}V + \theta - \frac{1}{\eta}\left(\psi(\theta) - \left(1 - \hat{\theta}\right)\right)$, where $\psi(\theta) = \int_{\hat{\theta}}^{1} d\psi(x)$ is a measure of the Lagrange multipliers. The innovator's payment is given by $\bar{u}(\theta) = u^o(\theta)$.
- On $[\theta_1, 1]$ there is a downward distortion, and $\bar{q}(\theta) = \frac{1}{\eta}V + \left(\theta - \frac{1}{\eta}\,\hat{\theta}\right)$ and $\bar{u}(\theta) = u^o(1) - \int_{\theta}^{1} \bar{q}(s)ds.$

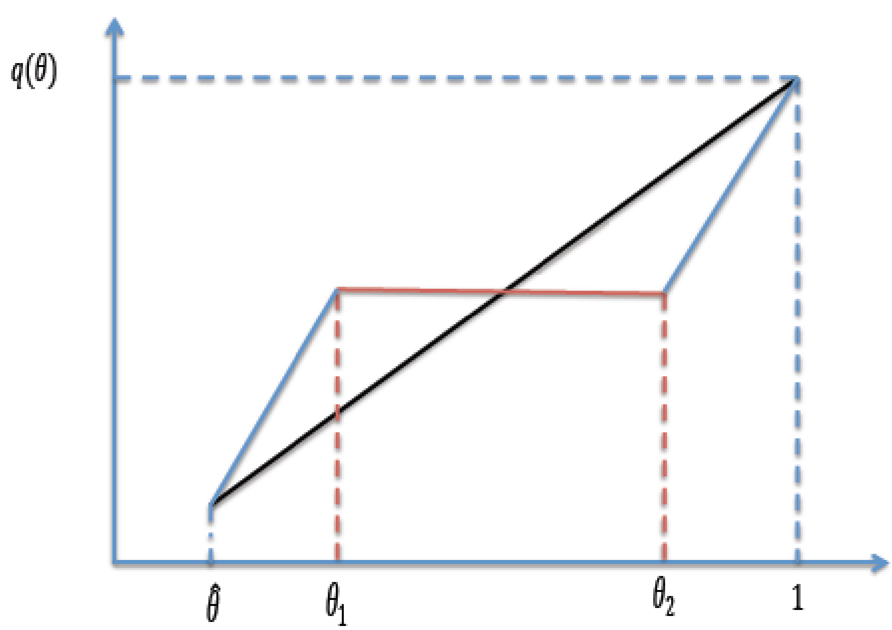
Proposition 4 establishes that in the region $[\hat{\theta}, \theta_1]$ innovators are more responsive to changes in the outside option. In particular, innovators have incentives to over-report their ability type. The result is an over-production of blueprints with respect to the full information case. The first part of the proposition shows that as the proportion of the innovator's type allocated into R&D increases, the reservation utility increases. It becomes more attractive for less able innovators (the lower type) and therefore is optimal for developers to incentivize an upward distortion.

As the participation constraint is binding, there is a region in which the quantity that maximizes the profit of developers is not monotonic. For intermediate abilities, principals face a conflict between incentive compatibility constraints and the minimization of informational rents.

In this case, in order to restore the incentive compatibility constraints, the developers must propose the same transfer scheme for innovators with abilities $[\theta_1, \theta_2]$ independently from the incentives that encourage the agent to over- or under-report their ability.

In the region that lies the interval $[\theta_2, 1]$ underproduction of blueprints with respect to the full-information case occur. In this case, as ability increases, innovations are more costly in terms of effort and innovators tend to under-report their ability. The shape of the optimal contract is given in the next figure.

Figure 2: Optimal Compensation Scheme for Innovators



This kind of compensation scheme can be found in high-tech firms and financial services industries. For instance, in the software industry high variance in the return on innovation is one reason explaining why developers are likely to pay more for star workers. As documented by Andersson et al. (2009), compensation for talented innovators in the software industry is on average twice as high as innovators' salaries in other industries. In addition, there are firms that pay more to loyal workers. Those who stay with a firm for five years can expect higher earnings, including stock options or other benefits. The second example is in the financial industry, where CEO compensations increase as the size of the firm increases. Celerier (2010) shows that in France there is a significant premium in the financial sector associated with the skewedness of wage and return on seniority.

7. Conclusions

We have presented an endogenous growth model with non-observable heterogeneity under adverse selection. The main result of this study is that heterogeneity introduces a new scaling effect that is important in the determination of the growth rate. In addition, adverse selection has a negative impact on economic growth as it increases dispersion in the productivity of innovators. Equilibrium contracts thus entail greater selection of talented workers in R&D activities and higher profits for the developer compared to the full- information case.

We also analyze the situation in which there are several principals with adverse selection. The main results establish that there are countervailing incentives for innovators that affect the total production of blueprints in the economy and therefore the probability of innovation. In addition, competition can be welfare-enhancing and can reduce rents for the developer in the production of intermediate goods. Nonetheless, this result does not take into account the potential for communication and information-sharing between developers. This is an interesting extension for future research.

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Appendix

Proof of proposition 1

In the symmetric case, from the first-order condition [12], solving for $x_i^{fb} = x^{fb} = \theta^{\hat{f}b} A\alpha^{\alpha\,/\,(1-\alpha)}$, and replacing the production function for the symmetric case yields $Y^{fb} = \theta^{\hat{f}b} A\alpha^{(\alpha/(1-\alpha))}$.

Therefore, when using the aggregate resources constraint, aggregate consumption is characterized as $C^{fb} = \theta^{\hat{f}b} A\alpha^{(\alpha/(1-\alpha))}(1-\alpha\hat{}\alpha)$, and the first set of allocations is obtained. Next, the total amount of blueprints is obtained from the first-order condition [8]$c_t^w = c_t^I - A_t e_t^2\,/2$, and replacing the optimality for blueprints [9] yields:

$$q^{fb} - \theta = \lambda\sigma\frac{\eta}{\mu}. \tag{49}$$

Since $\frac{\exp^{-\rho t}}{c_t^w} = \mu$, solving for $\frac{\eta}{\mu}$ for [11] gives:

$$\frac{\eta}{\mu} = \frac{(1-\alpha)\alpha^{(\alpha/(1-\alpha))}}{\lambda\sigma(q^{fb}+\theta^{\hat{f}b}-\theta)} \tag{50}$$

Substituting expression [50] with [49], the expression for q^{fb} is obtained. The second part is related to the steady-state growth rate. Note that as optimal final output, intermediate goods and aggregate consumption are proportional to the aggregate stock of knowledge, the growth rate is equal to the productivity growth rate. Using the optimal number of blueprints q^{fb},the productivity growth rate is given by:

$$g^{fb} = \lambda\sigma\frac{(1-\theta^{\hat{f}b})}{2}\left[\sqrt{1+\theta^{\hat{f}b\,2}+4(1-\alpha)\alpha^{(\alpha/(1-\alpha))}}\right] \tag{51}$$

The last part of the proposition concerns the characterization of the productivity thresholds $\theta^{\hat{f}b}$. Using the first order condition [10] and the fact that $\frac{\exp(-\rho t)}{e_t^w} = \lambda\sigma\eta$, dividing all expresions by η and replacing the optimal amount of intermediate goods yields:

$$-\lambda\sigma e\,/\,2 + \frac{\mu}{\eta}\left[(1-\alpha)\theta^{\hat{f}b}\,\alpha^{(\alpha/(1-\alpha))}\right] + \lambda\sigma\int_{\theta^{\hat{f}b}}^{1} q(\theta)dF(\theta) = -g_\eta \tag{52}$$

Where $g_\eta = \frac{\dot{\eta}}{\eta}$. As q^{fb} is stationary variable and expression [50] implies that $g_\eta = g_\mu = -g_{c^w} - \rho$then as g_{c^w} steady-state grows at the rate of the technology g_A, then $-g_\eta = g_A + \rho$.

Similarly, $g_A = \lambda\sigma \int_{\theta^{\hat{f}b}}^{1} q(\theta)dF(\theta)$can be simplified as:

$$-\lambda\sigma e \;/\; 2 + \frac{\mu}{\eta}\left[(1-\alpha)\theta^{\hat{f}b}\,\alpha^{\left(\alpha/(1-\alpha)\right)}\right] = \rho \qquad [53]$$

The next expression describes the level of effort for μ/η. Therefore, equation[53] collapses to all polynomial of parameters denoted by $\Psi(\hat{\theta})$:

$$\Psi\left(\theta^{\hat{f}b}\right) = \sqrt{\frac{\theta^{\hat{f}b} + 4(1-\alpha)\alpha^{\left(\alpha/(1-\alpha)\right)}}{2}} - \sqrt{\frac{\rho^2 + 2\theta^{\hat{f}b}(1-\alpha)\alpha^{\left(\alpha/(1-\alpha)\right)}(\sigma\lambda)^2}{(\sigma\lambda)}} - \left(\frac{\theta}{2} + \frac{\rho}{\lambda\sigma}\right) \qquad (54)$$

Consequently, the polynomial $\Psi\left(\theta^{\hat{f}b}\right)$is studied in the interval of parameters $\theta\,\epsilon[0,1]$. The aim is to show that there is a number M such that $\Psi(0) < M < \Psi(1)$ or vice versa. Characterising $\Psi(0) = \sqrt{2(1-\alpha)\alpha^{\left(\alpha/(1-\alpha)\right)}} - \frac{\rho}{\sqrt{\lambda\rho}}\left[1 + \frac{1}{\sqrt{\lambda\rho}}\right]$and for $\Psi(1) = \sqrt{\frac{1+4(1-\alpha)\alpha^{\left(\alpha/(1-\alpha)\right)}}{2}} - \sqrt{\frac{\rho^2+2(1-\alpha)\alpha^{\left(\alpha/(1-\alpha)\right)}(\sigma\lambda)^2}{(\sigma\lambda)}} - \left(\frac{1}{2} + \frac{\rho}{\lambda\sigma}\right)$. Then for standard values of $0 < \rho < 1, 0 < \lambda < 1, \sigma > 1$ it has $\frac{\delta\Psi(1)}{\delta\alpha} < 0$. As $\Psi(\theta^{\hat{f}b})$is continuous for all $\theta^{\hat{f}b}\,\epsilon[0,1]$and in particular for $M = 0$, the intermediate value theorem applies. Therefore, the polynomial has a root between 0 and 1. The following graph shows an example of this.

Proof of proposition 2

Replacing equation [28] in the no-arbitrage condition in the asset market (equation 30), we obtain the equilibrium value of blueprints:

$$q^*(\theta) = \frac{\lambda\tilde{\pi}\,\hat{\theta}}{\rho+\beta} + \theta \tag{55}$$

Replacing markup in the demand for intermediate goods, we obtain $x_t^* = \alpha^{\frac{2}{1-\alpha}} A_t\,\hat{\theta}$. This means that total output in the economy is given by $Y_t = \alpha^{\frac{2\alpha}{1-\alpha}} A_t \hat{\theta}$, and total profits for the developers are $\pi_t = \tilde{\pi} A_t \hat{\theta}$. In the balanced growth path for symmetric industries, we have $g = g_c^I = g_c^W = g_y = g_A$. Replacing this value in [6] we obtain the productivity growth rate. The rate of growth of the economy is therefore:

$$g = g^* = (1-\hat{\theta})\left[\hat{\theta}\left(\frac{\sigma\lambda^2\tilde{\pi} + (\rho+\beta)}{2(\rho+\beta)} + \frac{1}{2}\right)\right] \tag{56}$$

As preferences are logarithmic, and as aggregate consumption grows at the same rate as technology, the interest rate behave in the same way. Wages are proportional to the aggregate stock of knowledge, then grows at the rate of technology.

$$r_t = \rho + g^*, w_t = (1-\alpha)\alpha^{\left(2\alpha/(1-\alpha)\right)} A_t, p = \frac{1}{\alpha} \tag{57}$$

Productivity cur-off is determined by participation constraint. As there is free entry in R&D activity, we obtain the payment for the innovator in equilibrium conditions, according to the level of productivity θ and the total number of blueprints:

$$\int_{\hat{\theta}}^{1} \tau(\theta) dF(\theta) = \bar{\tau} = Ae^*(e^* + E_\theta(\theta)) \tag{58}$$

Replacing the total payment for innovation with all selected types of R&D $\theta\epsilon, 1]$ in the participation constraint [27], we obtain $\frac{(e^*)^2}{2} + e^*\theta = (1-\alpha)\alpha^{\left(2\alpha/(1-\alpha)\right)}$. For $\theta = \hat{\theta}$, by replacing [55] and solving for a uniform distribution, we find that the productivity cur-off is determined by: $\hat{\theta} = \sqrt{\frac{2(\rho+\beta)}{\lambda\sigma[\tilde{\pi}\lambda+1]}} > 0$.

Proof of proposition 3

The proof is similar to the case of full information; however, with asymmetric information the virtual surplus is added, captured by the inverse of the hazard rate. Them, replacing equation 43 in the non-arbitrage condition for asset markets, equation 30, we obtain that $q^{AI}(\theta) = \frac{\lambda\tilde{\pi}\hat{\theta}^{AI}}{(\rho+\beta)} + \left(\theta - \frac{(1-F(\theta))}{f(\theta)}\right) < q^{*}(\theta)$ as $\Delta(\theta)$ is increasing on θ then $q^{AI}(\theta) < q^{*}(\theta)$. Replacing this expression in the rate of growth of the economy, we obtain:

$$g^{AI} = \left(1 - \hat{\theta}^{AI}\right)\left[\hat{\theta}^{AI}\left(\frac{\sigma\lambda^{2}\tilde{\pi}}{(\rho+\beta)} + \frac{\lambda}{2}\right)\right] < g^{*}$$

To find the cut-off of the participation constraints, we replace the value for $q^{AI}(\theta)$, in this sense, the equilibrium cur-off is given by:

$$\hat{\theta}^{AI} = \left(\sqrt{\delta^{2} + a\left(\delta^{2}/2\omega\right)} + \delta\right)/\left(\delta^{2} - 2\right) > \theta^{*} \qquad (59)$$

Where $\omega = (1-\alpha)\alpha^{(2\alpha/(1-\alpha))}$ and $\delta = \frac{\tilde{\pi}\lambda}{(\rho+\beta)}$.

Proof of proposition 4

The Lagrange function for this problem is:

$$L = max \int_{\hat{\theta}}^{1} \left[\lambda q(\theta) V_t - A_t \left(\frac{q_t - \theta}{2} \right)^2 - U^I(\theta) \right] dF(\theta) + \mu q(\theta) + \int_{\hat{\theta}}^{1} \left(U^I(\theta) - U^o(\theta) \right) d\psi(\theta)$$

$$[q(\theta)]: [\lambda V_t - A_t(q_t - \theta)] f(\theta) + \mu \tag{60}$$

$$[U^I(\theta)]: -f(\theta) + \psi(\theta) = \dot{\mu}(\theta) \tag{61}$$

Solving [61] gives $\mu(\theta) = F(\theta) - \psi(\theta)$

Then, the first-order condition entails:

$$\lambda V_t = \left(\frac{\psi(\theta) - F(\theta)}{f(\theta)} \right) + A_t(q_t - \theta) \tag{62}$$

with $\psi(\theta) = \int_{\hat{\theta}}^{1} d\psi(x)$, which is a random measure of the Lagrangean multipliers. Evaluating when the participation constraint is binding $\psi(\theta) = 1$ or when $\psi(\theta) = 0$, the result yields.

Monotonicity constraint:

Innovators decide on their level of effort in each period, according to the following ICC:

$$\theta\epsilon \underset{\tilde{\theta}}{\arg max} \left(u^I(\tilde{\theta}) - \frac{e(\theta)^2}{2}\right) \text{ for all } \theta\epsilon\ \Theta \tag{63}$$

Therefore, we restrict our analysis to a set of announcements about the innovator's productivity, θ, that satisfies truthful reporting strategies. The innovator's preferences satisfy the Spence-Mirrlees condition:

$$\frac{\partial}{\partial\theta}\left(\frac{\partial u^I/\partial e}{\partial u^I/\partial\tau(\theta)}\right) = -e(\theta) < 0 \tag{64}$$

Condition [64] establishes that the marginal rate of substitution between effort and the innovator's payment decreases with productivity. Therefore, the more efficient the agent, the lower the wage required to bring about a set level of effort. The analysis is thus restricted to effort functions that increase the agent's efficiency.

The participation constraint can be expressed in terms of the value function:

$$u^I(\theta) = \underset{\tilde{\theta}}{max}\left(c_t^I(\tilde{\theta}) - At\frac{(q(\tilde{\theta}) - \theta)^2}{2}\right) = c^I(\theta) - A_t\frac{(q(\tilde{\theta}) - \theta)^2}{2}$$

Thus, the first-order condition for type $\tilde{\theta}$ is thus:

$$\frac{dc^I(\tilde{\theta})}{d\tilde{\theta}} - A_t\left(q(\tilde{\theta}) - \theta\right)\frac{dq(\tilde{\theta})}{d\tilde{\theta}} = 0$$

Truthful reporting strategies must satisfy:

$$\frac{dc^I(\tilde{\theta})}{d\tilde{\theta}} - A_t\left(q(\tilde{\theta}) - \theta\right)\frac{dq(\tilde{\theta})}{d\tilde{\theta}} = 0 \text{ for all } \theta\epsilon\ \Theta \tag{65}$$

It is also necessary to satisfy the second-order conditions:

$$\frac{d^2c^I(\theta)}{d\theta^2} - \frac{d\tilde{q}^2(\theta)}{d\theta^2}[1 - (\tilde{q}(\theta) - \theta)] + \frac{d\ \tilde{q}(\theta)}{d\theta} \leq 0 \tag{66}$$

Differentiation [65] with respect to $\tilde{\theta}$ we obtain:

$$\frac{d^2c^I(\tilde{\theta})}{d\tilde{\theta}^2} - \frac{dq^2(\tilde{\theta})}{d\tilde{\theta}^2}\left[1 - \left(q(\tilde{\theta}) - \theta\right)\right] \leq 0 \tag{67}$$

Under truthful strategies $\theta = \tilde{\theta}$, replacing [67] by [66] implies:

$$\frac{dq}{d\theta}(\theta) \leq 0 \tag{68}$$

These are the monotonicity constraints for blueprints. Using the envelope theorem, the following must be satisfied:

$$\frac{dU^I}{d\theta}(\theta) = A(q(\theta) - \theta) \tag{69}$$

Therefore, integrating [69] from 0 to 1-types we can rewrite the innovator's indirect utility as follows: $U^I(\theta) = U^I(\theta) + \int_0^1 (q(x) - x)dx$. Nevertheless, $U^I(\theta) = \overline{\omega}(1 - \hat{\theta})$as the agent has another option that represents the wage offered by final goods sector. The indirect utility function of the contract is given by $U^I(\theta) = c^I(\theta) - \frac{(q(\theta)-\theta)^2}{2} = \overline{\omega}\left(1 - \hat{\theta}\right) + \int_\theta^1 (q(x) - x)dx$. Therefore, the payment scheme for the innovator is according to:

$$c^I(\theta) = A\left(\frac{(q(\theta)-\theta)}{2} + \overline{\omega}\left(1 - \hat{\theta}\right) + \underbrace{\int_\theta^1 (\tilde{q}(x) - x)dx}_{\text{Information rent}}\right) \tag{70}$$

The participation constraint under asymmetric information is similar to the symmetric information case, but now the developer must provide an information rent to the agent to reveal their private information. The total payment to the innovator must be at least equal to the reservation utility plus the disutility of effort. Accordingly, payment increase with the level of effort