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IDEAS-DRIVEN GROWTH: THE OECD EVIDENCE

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ABSTRACT

This paper estimates the parameters of the ideas production function crucial to recent ideas-driven growth models. Using U. S. patents granted to residents in OECD countries in order to construct the stock of commercially used ideas, we provide evidence for two main findings. First, at the level of the production of ideas, we find evidence of increasing returns to scale in the stock of ideas and number of researchers, but marginal decreasing returns in each one of these factors. Second, we provide evidence of the association between ideas growth and economic growth, for the OECD as a whole, in the long run.

Keywords: *Innovation; spillovers; ideas-driven growth; patents; public intervention*
JEL classification: 031; 040

RESUMO

Neste artigo estimámos os parâmetros de uma função de produção de ideias, tarefa crucial para avaliar a adesão dos modelos recentes de alteração tecnológica endógena à evidência empírica. Utilizando os dados sobre patentes norte-americanas, atribuídas a residentes nos países da OCDE, de modo a construir stocks de ideias comercializáveis, o presente trabalho fundamenta duas conclusões principais. Primeiro, ao nível da produção de ideias, verificámos a existência de rendimentos crescentes à escala no stock de ideias e número de investigadores, mas rendimentos marginais decrescentes em cada um destes factores. Em segundo lugar, verificámos uma associação entre o crescimento das ideias e o crescimento económico, para a OCDE como um todo, no longo prazo.

Palavras-chave: *Crescimento endógeno, externalidades, inovação, intervenção pública, patentes.*
Classificação *JEL*: 031, 040.

1. INTRODUCTION

A crucial economic attribute of knowledge, highlighted in recent models of endogenous growth, is that ideas are both non-rival and cumulative. Non-rivalry implies that one person's use of an idea does not prevent another person from using it at the same time. Moreover, ideas are cumulative: one precise idea leads to another idea which may in turn lead to yet further ideas. Analysis of these attributes of non-rivalry and cumulative feedback has led growth theorists to speculate that investment in the generation of ideas can be the engine of long-run growth.

Ideas are nonrivalrous goods, but they vary to a large extent in their degree of excludability. Nonrivalrous goods that are basically unexcludable are labelled public goods. The public-good nature of knowledge, that is, non-rivalry in association with the impossibility of excluding someone from its benefits, leads us to expect market failure. When others reap the benefits of someone's new ideas, market forces alone are unlikely to generate the optimal level of investment in knowledge — implying a need for government intervention.

A crucial difference between the neo-classical and the new growth theories concerns the question of whether the long-run rate of growth of the economy is an exogenous constant, or whether it can be influenced by public policy. To the extent that technological change is endogenous in ideas-driven models, we expect the generation of ideas to have long-run growth effects in addition to the conventional prediction of level effects. Putting it another way, the question is whether policies and institutions that influence the rate of accumulation of physical capital and/or knowledge have long-run effects on the *level* of economic activity or on its *rate of growth*[1].

Another crucial debate within the new growth theory is centred on the role of the "ideas" sector in sustaining equilibrium productivity growth. In Romer's seminal model of endogenous technological change, productivity growth is driven by a constant allocation of resources to an ideas-producing sector (Romer, 1990), a result that depends critically on strong positive intertemporal spillovers in the ideas production. Specifically, to generate ideas-driven growth, ideas sector productivity must increase proportionally with the stock of ideas already discovered. The

[1] However, for purposes of practical policy-making, this distinction may be relatively unimportant — if the 'long-run' never arrives. If economies are subject to shocks of sufficient magnitude and frequency, it may be difficult, if not impossible, to tell how the long-run growth path really looks like.

significance of ideas-driven growth therefore depends on whether the ideas production function satisfies this critical property. To evaluate this claim, several authors have examined the relationship between the total factor productivity (TFP) growth rate and the size of the workforce devoted to the production of ideas (Jones, 1995; Coe and Helpman, 1995).

The ideas-driven model, with the assumptions made by Romer, predicts that expansion in the number of researchers leads to a permanent increase in the TFP growth rate. In contrast, the empirical evidence suggests that most OECD economies have increased the size of their R&D workforce, while experiencing (at best) constant TFP growth rates. This weak relationship between the number of reserchers and the TFP growth rate has led some to question the viability of ideas-driven growth for the long run (Jones, 2001)[2].

This paper aims at contributing to the empirical understanding of the economic growth by estimating the shape of the ideas production function and the strength of the intertemporal spillovers in ideas. We shall examine the pattern of patents granted in the United States to inventors from OECD countries, and use the patent counts to construct a stock of commercially relevant ideas. This stock of ideas, together with the number of researchers, will allow us to evaluate the determinants of the flow of new ideas directly. First, we'll separate ideas production from the more general relationship between the ideas sector and the overall productivity growth. Accordingly, by computing the stock of ideas over time, we'll be able to estimate explicitly the strength of the spillover from ideas-to-ideas. But, if the generation of ideas is the engine of growth, we should expect to find that embodied human capital – skills and abilities – also affect long-run growth. Ideas do not reproduce themselves without the input of highly skilled researchers. So, we'll compute the elasticity of new ideas with respect to the number of researchers, too.

Secondly, we'll address the long-run evolution of the GDP per worker and of ideas. In order to attain this goal we'll examine the statistical association between the evolution of measured ideas and the GDP per worker variation, in the OECD as a whole.

The following section describes the characteristics of ideas-driven models that have been identified by recent theories of economic growth and presents the theory that

[2] Several authors instead argue that productivity growth rates can be explained by factor accumulation including the accumulation of human capital (Barro, 1991; Mankiw, Romer, and Weil, 1992).

supports the model used in empirical tests. In section 3, we explain the construction of our stocks of commercially used ideas and the data used. The empirical findings about spillovers are depicted in section 4. Section 5 compares the evolution of ideas with the economic growth. Finally, section 6 concludes.

2. THEORY

Several authors have discussed the attributes of knowledge that make it significantly different from the accumulation of items of physical capital (Romer, 1990, 1993). These special attributes are: non-rivalry and dynamic feedback. Once a new idea has been generated, it can be used simultaneously and cost-free in many different processes. Furthermore, the idea can serve as an example and inspiration for further research. But the properties of non-rivalry and feedback also suggest that the market may fail to allocate sufficient resources to knowledge generation because individuals have difficulty in establishing and enforcing property rights over their new ideas – some of the benefits of an innovation are likely to accrue to others. When the private return to innovation is less than the social return, governments need to subsidise R&D.

R&D expenditures typically constitute, for advanced economies, only a few percent of GDP — perhaps one tenth of the expenditure devoted to investment in physical equipment and structures. In a standard growth accounting framework, variations in the research effort will, therefore, explain very little of the differences in growth rates between countries. But the point of much of the new growth theory is precisely that if knowledge spillovers are substantial, and if knowledge exhibits dynamic feedback effects, then even small changes in the resources devoted to the production of knowledge may result in substantial changes in economic growth[3].

In order to approach the empirical tests, we'll start with the basic formulation of an endogenous growth model. In a simple formulation of a varieties model, output, Y, is given from an aggregate production function as:

$$Y = BL_Y^{\,1-\alpha} \int_0^A x_j^{\,\alpha} dj \tag{1}$$

[3] Grossman and Helpman (1991) calibrate their model to match the US growth experience, and emphasize this point. They predict that, whilst business investment constitutes around ten percent of GDP, investment in R&D — the engine of growth — needs to comprise as little as 1.6 percent to generate economic growth of 2.5 percent per year.

Where B is an exogenous technology factor, L_y is labour input, x_j is the quantity employed of intermediate input of type j[4], A is the number of varieties of intermediate products that are currently known and used and $0 < \alpha < 1$.

In Romer's seminal model of endogenous technological change, there are three sectors: one sector producing final goods, one sector producing intermediate-goods and another making research and development (R&D). So, the output stream, Y, can be consumed, used as intermediate inputs to production or allocated to R&D.

In equilibrium, each intermediate is employed at the same level, $x = K/A$, where K represents capital stock. Hence, equation (1) can be written as:

$$Y = BL_y^{\;1-\alpha} A\left(\frac{K}{A}\right)^{\alpha} \qquad (2)$$

Or, presenting production function in its more common form:

$$Y = BK^{\alpha}\left(AL_y\right)^{(1-\alpha)} \qquad (3)$$

Describing the way as capital stock, K, and labour input, L_y, combines to produce output, Y, using the stock of ideas A. Technological progress occurs through R&D outlays that rise A over time. For a given technological level A, equation (3) exhibits constant returns to scale. However, when we recognise the non-rival nature of ideas (Romer, 1990), then there are increasing returns. In other words, the production function exhibits constant returns to scale in capital and labour inputs, and therefore must exhibit increasing returns with respect to all three inputs: K, L_y, and A.

For simplicity, we admit that capital and labour accumulates as in the Solow (1956) model: capital accumulates according to some given investment rate, s_k, and depreciates at the exogenous rate δ:

$$\dot{K} = s_k Y - \delta K \qquad (4)$$

Total labour (L) in the economy, is used either to produce output (L_y), or to produce ideas (L_A):

$$L = L_y + L_A \qquad (5)$$

[4] Alternatively x_j may be treated, for simplicity, as non-durable. In that case x_j represents the service flow from the jth type of capital good.

And grows exponentially at some constant and exogenous rate *n*:

$$L_t = L_0 e^{nt} \tag{6}$$

In the long run, along a balanced growth path, two important questions may arise: what is the growth rate predicted by the model? And, what is the rate of technological progress? The first question has an answer, which is similar to the one that occurs in the neo-classical growth model, that is, if there is a constant fraction of the population in the production of ideas, the model predicts that all per capita growth is due to technological progress. In other words, per capita output, the capital/labour *ratio* and the stock of ideas must grow at the same rate, along a balanced growth path. That is, no technological progress means no growth.

In order to answer the second question, we need to draw the ideas production sector, and specifically the way new ideas are invented. One can imagine several possibilities for the rate at which researchers discover new ideas. This rate may be a constant, or it can depend on the stock of ideas that have already been invented, or even it may depend on the number of researchers. In the simplest case, the number of new ideas, $\dot{A}$, is equal to the number of researchers, L_A, multiplied by the rate at which they discover new ideas, χ. That is, $\dot{A} = \chi L_A$

Every individual researcher views his produced ideas as new, and feels constant returns on his investigation. He or she produces χ new ideas. However, in the economy as a whole, the aggregate research effort doesn't generate an output equal to the resulting sum of the individual efforts. It is very plausible that some different researchers find out the same commercially relevant ideas. So, we can represent by λ a negative externality that result of duplication, and the aggregate function takes the form:

$$\dot{A} = \chi {L_A}^{\lambda} \tag{7}$$

Where λ is a parameter between 0 and 1. But the rate χ, itself, may depend on the number of ideas already discovered, that is:

$$\chi = \pi A^{\phi} \tag{8}$$

Where ϕ specifies the grade of dependence between χ and A, and $\pi > 0$ is a constant[5]. With the equation 8, if $\phi > 0$ the productivity of research increases with the stock of the ideas that have already been discovered. If we assume $\phi = 1$, the number of new ideas is also proportional to the stock of ideas discovered in the past and the growth rate of ideas becomes itself proportional to the number of researchers. In this case, like in Romer's model, it is the number of people engaged in research and development that drives long-run growth.

In fact, in addressing the problem of limits to human capabilities, Paul Romer emphasises the distinction between human capital — the skills and abilities that are embodied in individual humans —, and ideas, which are disembodied knowledge. He focuses on the properties of the latter category, the world of ideas and research, supposing that there is sufficient dynamic feedback in the research sector to generate endogenous growth and that the scope for developing new ideas is limitless. According this, the mathematical representation of the generation of new ideas, in Romer's model, is:

$$\dot{A} = \pi L_A A \,. \qquad (9)$$

Where $\dot{A}$ represents the number of new ideas created at time *t*, L_A represents the amount of human capital, or the number of researchers, devoted to innovation, and *A* represents the stock of ideas existing until time *t*.

As it is apparent from equation 9, Romer assumes that the productivity of the research is directly proportional to the extant stock of knowledge[6]. In the accumulation of disembodied ideas, rather than embodied skills, it is indeed plausible to suppose that the level of current output might be directly proportional to the size of the stock. The more ideas that we have to draw on, the easier it is to generate new ones. Moreover, ideas do not necessarily disappear when their developer dies — they can typically be recorded and transmitted at minimal cost. Implicit in Romer's formulation of research output is the idea that there is an evenly distributed and infinite universe of potential

[5] π is usually assumed as constant. But, π may depend, within other factors, on institutions and political choices, on the more or less innovation-friend environment, and on the linkages within innovation infrastructure and industrial clusters.
[6] This is the "standing on shoulders" hypothesis of knowledge accumulation, so labeled by Jones (1998), in reference to Isaac Newton's disclaimer: "If I have seen farther than others, it is because I was standing on the shoulders of giants".

ideas waiting to be discovered. So, a given amount of research effort will produce a predictable number of new ideas[7].

Jones (1995, 1998) criticises some of the key assumptions underpinning the Romer's model. In particular, he suggests that knowledge formation may become more difficult over time as the easy ideas are discovered first, leaving subsequent researchers with a pool that has been "fished out". He also suggests that researchers may often duplicate each other's efforts: "stepping on toes" rather than "standing on shoulders". So, according to Jones, the ideas production function took the form, which is obtained by combining equation 7 with equation 8[8]:

$$\dot{A} = \pi {L_A}^{\lambda} A^{\phi} \qquad (10)$$

In the ideas production function 10, two kinds of externalities may be represented. One, related to the R&D workers (λ) and the other associated to the existing stock of ideas, which occurs with $\phi \neq 0$. For instance, $\lambda < 1$ may reflect a negative externality associated with duplication: some of the ideas created by a researcher may not be new to the economy as a whole. On the other hand, we can think of existing externalities associated to the stock of ideas: when $\phi > 0$ the R&D productivity increases with the already discovered stock of ideas, reflecting a positive knowledge spillover; when $\phi < 0$, the "fishing-out hypothesis", R&D productivity decreases with the increased stock of ideas: the ideas discovered first are the easiest to find. So, knowing ϕ and λ is essential to contribute to the ideas driven-growth debate.

Now we can think about the second question: what is the rate of technological progress? As Jones (1998) shows, the answer is given by the formula:

$$\frac{\dot{A}}{A} = \frac{\lambda n}{1-\phi} \qquad (11)$$

That is, the long-run growth rate of the economy is determined by the parameters of the production function of ideas and the rate of growth of researchers, which is ultimately given by the population growth rate, *n*. If λ=1 and ϕ=0, ideas production function takes the form $\dot{A} = \pi L_A$ and researchers productivity is the constant π,

[7] Otherwise, we can allow the fluctuation of the discovery rate, as Aghion and Howitt (1998) summarized in their discussion of General Purpose Technologies.

[8] Equation 10 can also be seen as a more general form of equation 9, if we are assuming λ=1 and ϕ=1.

meaning that there are no negative duplication externalities in the research process and the productivity of a researcher in the present is independent of the ideas discovered in the past. If L_A keeps constant, with $\lambda=1$ e $\phi=0$, the economy generates a constant number of new ideas in every period, meaning that the stock of ideas growth rate decreases over time, though technical progress don't ceases. In order to have growth, the number of new ideas must grow over time. One way of achieving this outcome is to assume that the number of researches shall rise over time, too.

Dropping $\phi=0$ restriction, there is a special case in which a constant research effort can generate long-run sustained growth. If $\lambda=1$ and $\phi=1$, as in the model of Romer (1990), the differential equation $\dot{A}/A=\pi L_A$ which leads technological evolution, is linear and the model predicts that research productivity increases over time, even in the presence of a constant number of researchers. But, with these assumptions, an increase in the dimension of the economy leads to an increase in the per capita growth rates of the economy and generates an infinite growth in the long run. This prediction wasn't corroborated by time. On the contrary, in the last half-century the economic growth rate was actually rather inferior to the researchers' growth rate[9].

But the fact that the number of researchers is growing more than per capita GDP, doesn't necessary mean that there aren't increasing returns in investigation, or positive knowledge spillovers. It only means that the empirical experience indicates that the case of $\phi=1$ is highly unreliable[10].

Assessing if function 10 is empirically verifiable in OECD, and finding out the parameters λ and ϕ, are fundamental tasks to understand the dynamics of ideas generation and the way these ideas affect the economic growth. So, the next section reports the data and the process we have used to construct the stock of commercially relevant ideas, necessary to test empirically the ideas production function.

3. DATA AND THE STOCK OF IDEAS

In order to assess the empirical evidence, we'll start with equation 10. Taking natural logs, we have:

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[9] It's worth to note that in the late half-century the number of researchers registered has increased much more than the population, whose growth rate is generally pointed as a limit to the L_A growth.

[10] Also the case of $\phi>1$ doesn't seem very acceptable, as it implies acceleration in the economic growth rate, even with a constant population.

$$\ln \dot{A} = \ln \pi + \lambda \ln L_A + \phi \ln A \qquad (12)$$

Equation 12 may give estimates to the parameters λ and ϕ by Least Squares methods, considering $\ln \pi$ constant and assuming that we have data on $\dot{A}$, L_A, and A. For L_A we'll use researchers data of OECD. The use of the number of researchers supplied by the statistics, as proxy of L_A, is subject to critique. We are conscious that these figures exclude the effort of many small firms, so as the resolution of technical problems at the firm level, which generate improvements in products and processes. In order to estimate the ideas production function, in the absence of a better proxy, we use the number of researchers (full-time equivalent), given by OECD (MSTI database) as an index of the number of workers that create economically relevant ideas.

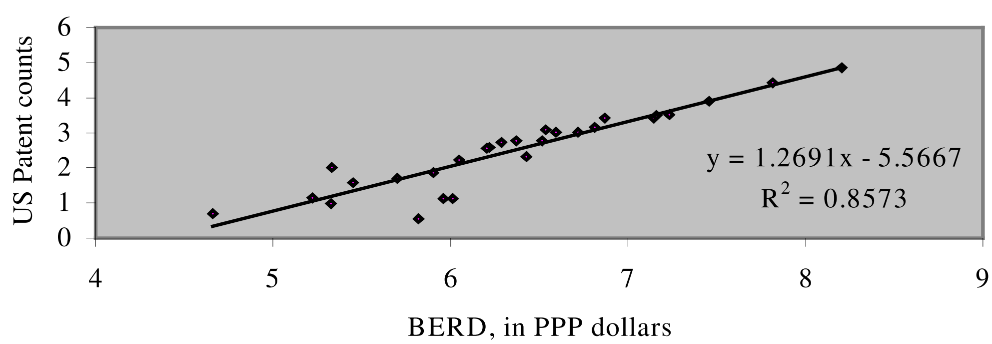
The choice of indicators for $\dot{A}$ and A deserves some additional comments. The most obvious indicators, in order to construct the stock of ideas (A) and the number of new economically useful ideas ($\dot{A}$), are the R&D outlays and the patent counts. Coe and Helpman (1995) have built stocks of ideas to which they have given the name of R&D capital stock for 21 OECD countries, plus Israel, making use of business sector research and development expenditure (BERD) data. In the present paper, we shall use utility patents granted in the United States to residents of OECD countries in order to construct the proxies of $\dot{A}$ and A. The main reasons to have chosen patent counts instead of BERD are as follow.

Theoretically, a patent does represent a minimal quantum of invention that has passed both the examination of the patent office, as to its originality, and the test of the investment of effort and resources by the inventor and his organisation into the development of this product or idea, indicating thus the presence of a significant expectation as to its final utility and marketability. These characteristics suggest patents as an output indicator of inventive activity appropriate to measure ideas and the stock of ideas. But, there is a correlation between business enterprise R&D expenditures (BERD) and patent counts, as we can observe in figure 1, which shows the association between BERD, for 28 OECD countries[11], in 1997, and patents granted in the United States to inventors residents in each one of those countries. Both

[11] Totality of OECD minus Luxembourg, which doesn't present data on R&D, and Slovakia whose data on patents are less reliable.

variables are presented in logarithmic scale[12]. It is apparent in figure 1 that there is a high positive correlation between the two variables (correlation coefficient = 0.995)[13]. But, besides high correlation, there is some evidence, that shows that the correlation is higher between total factor productivity (TFP) and patent counts, than between TFP and BERD (see Griliches, 1989; fig. 6 and Griliches, 1990, fig. 10).

Figure 1. Association between BERD and patent counts



Sources: OCDE (MSTI data base), and USPTO.

Patent use is subject to several critiques. The first, and the most emphasised, observes that not all inventions are patentable, and not all inventions are patented. Besides, the inventions that are patented differ greatly in quality, in the size of inventive output associated with them. In relationship to these critics we can always invoke the law of large numbers, like Scherer, (1965): The economic significance of any sampled patent can also be interpreted as a random variable with some probability distribution. Given the underlying heterogeneity, the question is to know whether our samples are large enough, in a way that authorises the use of the law of large numbers.

But, on the other hand, the increase in the number of patents granted, more than representing an increase in the economically useful ideas, could be the result of the rise of international trade, or the outcome of a stronger concern with the protection of

[12] To reduce the effects of the problems associated to the cycles in the grant of patents, we have considered the average of the number of patents in 1997 and 1998.

[13] The correlation coefficient would be even higher if we had excluded from the sample, Turkey, Poland and Czech Republic, for these countries present a dissonant pattern from the other OECD countries.

intellectual property rights, in the same way as it could reflect the existence of cyclical waves in the realisation important ideas[14].

The use of patent counts to draw the stock of economic useful ideas doesn't necessarily mean that patents are the only output of economically relevant innovation, or that patents are the ideal measure of such output. Instead, we merely assume that patents give a useful index of the general innovation activity. The crucial assumption that we adopt is that a constant fraction of innovation output is valuable enough in order to deserve a patent, and that the fraction is constant across economies.

With all these considerations in mind, we have measured the number of new ideas and the stock of commercially relevant ideas by the United States Patent and Trademark Office (USPTO) utility patents granted to inventors residents in the OECD countries[15]. The stock of ideas (*A*) is calculated from patent counts (*P*) granted by USPTO based on the perpetual inventory model:

$$A_t = (1-d)A_{t-1} + P_{t-1} \tag{13}$$

Where *d*, the obsolescence rate, means the rate of substitution of the old ideas by the new ideas.

The initial stock of ideas, A_0, is calculated as:

$$A_0 = P_0 \big/ (g+d) \tag{14}$$

Where *g* is the average annual logarithmic growth rate of patent counts over the period for which data were available, and P_0 is the patent counts for the first year for which the data on utility patents are available (in the present case 1963-1998 period). While *g* is country-specific, we admit that *d* is the same for all countries.

The most severe problem we face in constructing the stock of ideas is the arbitration of the obsolescence rate, *d.* Some models of endogenous growth, like Romer's, suggest that new ideas increase the stock of ideas without obsolescence of the older ideas. So

[14] It is convenient to discriminate cyclical fluctuations, associated to political and bureaucratic problems, from the cyclical waves, associated to innovations (Schumpeter, 1939, 1942; Freeman, 1982). In the first case, simple statistical measures can minimize their effects, while in the second case the wave has a meaning that we can't ignore in the result analysis.

[15] In calculating the stock of ideas we use only utility patents (patents of invention) and not total patent counts. The reason for this option is that we suspect that the different types of patents have different effects on the production of new ideas. Because the distribution of total patents by different types varies across countries, we need a weighting criterion to build a stock of ideas comparable across countries. In the absence of such criterion, we decided to use only utility patents, which correspond to the larger percentage in the total number of patents.

variety models seem more suitable to the estimation of the equation 12, because they take away the need of arbitration of the obsolescence rate. However, if we don't control obsolescence, the stock of ideas depends crucially on the time chosen to calculate the initial stock of ideas. In the absence of a cleverer method of determination of obsolescence rate, we have calculated the stock of ideas in four hypotheses: d=0%, d=5%, d=10% e d=15%.

4. SPILLOVERS

In the following empirical tests we'll consider two samples. The first one (sample-basis) comprises 27 countries of the OECD. In this sample we have considered every country of OECD except Luxembourg because this country doesn't report data about researchers, and the Czech Republic and Slovakia because data about patent counts don't allow us to construct a stock of ideas according the same criteria used for the other countries[16], that is, discriminate patents granted to residents in each country.

The second sample (reduced sample) contains the countries included in the sample-basis minus Poland, Portugal, Turkey, Greece, Mexico and Hungary. The exclusion of these countries is justified for two reasons. First, because they are the less developed countries, and so it is likely that growth pattern won't be the same as the other (more developed) countries. Secondly, the behaviour of technological indicators is also distinct. In these excluded countries, per capita technological indicators are either very low (Portugal, Turkey, Greece), or they exhibit, in several periods, negative growth rates (Poland, Mexico and Hungary). These characteristics indicate that technological accumulation follows a different path[17]. Besides, the low level and the negative growth rate of patent counts must contribute to extra measurement errors in the calculation of the stock of ideas.

Empirical results of the regressions are represented in two tables. In table 1, we present the estimates for sample-basis and in table 2, the estimates for the reduced

[16] We don't have the possibility of discriminating in the patent counts of the old Czechoslovakia between the patents that must be attributed to Czech Republic and those pertaining to Slovakia, in the time span between 1963 and separation of the two new republics.

[17] The exclusion of these countries is also based on other reasons. For instance, in Portugal, during 1988-1997 period, correlation coefficient analysis indicates that there isn't an ideas production function of the same kind as that of the reduced sample. In fact, correlation coefficient of number of researchers L_A, with the number of new ideas $\dot{A}$, was –0.3. On the other hand, the measured correlation between the stock of ideas A, and new ideas $\dot{A}$, was –0.58.

sample. In each table results are distributed in four columns, according to the obsolescence rate, *d*, used in the calculation of stock of ideas.

Table 1.

Ideas production function estimation results for OECD (sample-basis), 1998.

Obsolescence rate	*d* =0%	*d* =5%	*d* =10%	*d* =15%
Constant	-8.246* (-3.90)	-2.289** (-2.57)	-1.602** (-2.28)	-1.167+ (-1.96)
λ	1.122** (2.71)	-0.005+ (-0.04)	-0.026+ (-0.24)	-0.028+ (-0.31)
ϕ	0.261+ (0.96)	1.012* (12.70)	1.022* (15.89)	1.021* (17.62)
R^2	0.72	0.97	0.98	0.98

Source: Researchers — OCDE, MSTI database; Patent counts — USPTO. Notes: *t* statistics (White heteroskedasticity-consistent) in parentheses, * 1% signification level; ** 5% signification level; +Not significant.

In the estimates of table 1, we can discriminate two situations, according to the consideration, or not, of the obsolescence of ideas. In *d*=0% hypothesis, the explicative power of the model is lower and the elasticity of new ideas with respect to the number of researchers (λ), as expected, is larger than when we consider obsolescence. However, the high value of λ, indicating positive agglomeration externalities, doesn't seem realistic, because with $\lambda>1$, together with the growing number of researchers, means that the growth rate of ideas should rise without any boundary. With the obtained estimates of λ and ϕ, in the long run, per capita GDP should increase without any limit to infinite.

In the obsolescence hypothesis, the elasticity of new ideas with respect to the number of researchers (λ) loses it statistical significance. Additionally, λ estimate will become negative with the increase of the obsolescence rate. In spite of this weakness, let's consider the estimates to verify model behaviour. With *d* equal or superior to 10%, we face decreasing returns to scale, because the elasticity of ideas (ϕ) doesn't balance the negative value of λ. However, with a constant number of researchers, given the high elasticity of stock of ideas (ϕ>1), the growth rate of ideas would increase. But, with $\lambda < 0$ an increase of L_A would have as consequence the decrease of the growth rate of ideas, and so, of the economic growth rate.

These outcomes to the sample-basis are counterfactual: in the last forty years, at least, the per capita growth of income coexisted with growth of researchers. This counterfactual result, together with the loss of statistical significance, when the new ideas substitute the old ones, questions the appropriateness of the model to sample-basis of the OECD.

Let's analyse then the reduced sample (table 2). In the reduced sample, whatever *d*, the model presents a high explicative power, with a R^2 equal or superior to 97% and a *t* (White heteroskedasticity-consistent) statistic also significant at 1% level, excepting only the elasticity of the new ideas with respect to the number of researchers (λ) when $d \geq 5\%$. But even in this case, the coefficient keeps significant at the 5% level.

For any *d*, estimates of λ and ϕ are positive and less than 1. This means that in the ideas production function each one of the factors L_A and A have marginal decreasing returns. So, the increase in the number of researchers, either the increase in stock of ideas have a positive effect on the number of new ideas, but this effect is smaller and smaller as the respective factor increases. The obtained results also show, that the production of ideas is generated at increasing returns to scale, though that generation occurs in a small percentage beyond constant returns. Simultaneous increase of L_A and A generates a more than proportional increase in the number of new ideas $\dot{A}$.

Table 2

Ideas production function estimation results, for 21 OECD countries, 1998.

Obsolescence rate	d =0%	d =5%	d =10%	d =15%
Constant	-4.771* (-5.484)	-3.677* (-4.338)	-2.880* (-3.853)	-2.292* (-3.501)
λ	0.663* (3.122)	0.447** (2.288)	0.331** (2.090)	0.262** (2.017)
ϕ	0.467* (3.282)	0.642* (4.781)	0.732* (6.747)	0.786* (8.913)
R^2	0.97	0.98	0.99	0.99

Source: Researchers — OCDE, MSTI database; Patent counts — USPTO. Notes: *t* (White heteroskedasticity-consistent) statistic in parentheses, * 1% signification level; ** 5% signification level.

However, for any *d*, being the number of new ideas less than proportional to the stock of existing ideas ($\phi < 1$), the growth rate of ideas can only rise if there is an increase in number of researchers. With L_A constant $\dot{A}/A$ is decreasing, and the model doesn't generate per capita or per worker growth in the long run.

5. IDEAS GROWTH AND ECONOMIC GROWTH

The ideas driven model predicts that $\dot{y}/y = \dot{k}/k = \dot{A}/A$, with a constant share of the population employed in the production of ideas, in the long run, once attained the steady-state path. That is, the per capita output and the capital/labour *ratio* must increase at the same rate as the stock of ideas. This equality deserves an additional test.

In table 3, we report two types of ideas growth rates to the OECD countries[18]: the actual growth rate in 1998 and the long run trend. In the former we have used as $\dot{A}$ measure the average of the utility patent counts granted by USPTO from 1995 to 1998 and we have employed as denominator the measure of the stock of ideas in 1998, calculated as previously (equations 13-14), admitting obsolescence rates of 0% and 5%[19].

To assess the growth trend of ideas, we'll begin with the calculation of the stock of ideas for every year from 1963 to 2002, according the method and sources previously referred to, and afterwards we'll compute, by regression, with a continuous exponential function the instantaneous growth rate. The trend growth of GDP per capita and GDP per worker are measured for 1950-2000 e 1962-2000 periods, respectively, with trends instantaneous rates, which were calculated by us with PWT 6.1 (Heston, 2002) data, through the OLS method.

Table 3 shows that the growth rate of ideas is usually higher than growth trends of GDP per capita and GDP per worker. But table 3 also shows that the obsolescence rate is crucial to determine growth rate of ideas. Without new investigations about the pace with which new ideas substitute old ones, it is very difficult to present more accurate estimates of the growth rate of ideas, and consequently, a more truthful assessment of the precise figures of λ and ϕ.

[18] Czech Republic and Slovakia are excluded due to the paucity of data.
[19] The use of averaged count of patents is owed to the need of taking to account the bureaucratic cycles in the grant of patents. However, the consideration in the numerator of utility patents of 1998 alone, makes the growth rate of ideas higher, but it doesn't modify the conclusions obtained fort the relationship between per capita output growth and the growth of ideas.

Table 3

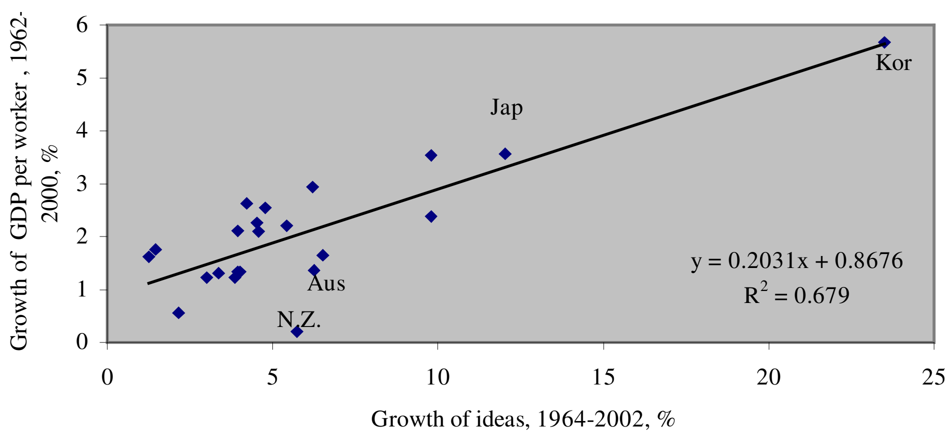
Ideas growth and growth trend of real GDP

	Ideas growth trend, 1964-2002		Ideas growth rate, 1998		Growth trend of:	
	(*d*=0%)	(*d*=5%)	(*d*=0)	(*d*=5%)	Real GDP per worker, 1962-2000	Real GDP per capita, 1950-2000
Germany	4.26	3.94	2.97	6.80	1.34***	2.06*
Australia	6.58	6.24	4.97	9.51	1.36	2.10
Austria	5.2	4.78	3.35	7.25	2.55	3.37
Belgium	5.25	4.58	4.90	10.28	2.10	2.82
Canada	4.23	3.86	4.20	9.10	1.23	2.21
Korea	23.54	23.50	24.28	29.31	5.68	5.73
Denmark	4.47	4.00	4.36	9.57	1.34	2.33
Spain	5.81	5.42	5.32	10.36	2.20	3.41
USA	1.85	1.25	2.20	6.64	1.62	2.27
Finland	9.94	9.79	7.88	12.83	2.38	2.99
France	4.29	3.95	3.28	7.34	2.11	2.84
Greece	2.62	2.03	2.45	7.02	2.15	3.28
Netherlands	3.66	3.36	2.94	6.94	1.30	2.43
Hungary	6.20	6.16	1.64	3.53	2.45*	1.55*
Ireland	10.41	9.78	6.70	11.21	3.54	3.29
Iceland	8.23	6.52	4.59	9.46	1.65	2.92
Italy	4.33	4.21	3.61	7.77	2.62	3.33
Japan	12.52	12.02	6.83	11.01	3.56	4.79
Luxembourg	5.98	6.21	2.99	6.09	2.94	2.87
Mexico	5.48	-1.81	0.00	6.65	-0.76	2.07
Norway	5.03	4.52	4.49	8.91	2.26	2.98
New Zealand	5.87	5.73	5.34	10.58	0.21	1.34
Poland	6.01	4.72	1.75	4.53	2.28**	1.23*
Portugal	2.87	2.27	2.97	7.70	2.89	3.89
United Kingdom	1.95	1.45	1.77	5.18	1.76	2.08
Sweden	3.58	3.00	2.71	6.94	1.23	2.16
Switzerland	2.26	2.16	1.65	4.82	0.56	1.68
Turkey	8.14	6.50	2.74	5.48	2.50	2.35

Source of calculations: PWT 6.1 (GDP per capita) and USPTO (patents). Notes: *Calculated only after 1970; ** Calculated only after 1979; *** Calculated only after 1990.

But, in terms of large trends, obsolescence rate seems to have a minor effect on the measured growth rate of ideas. The behaviour of the long-term growth trend of ideas allows us to make some comments about the equivalence between $\dot{A}/A$ and $\dot{y}/y$. First, the figures showed allow us to detect an association connecting the growth of ideas and economic growth, being the latter measured by real GDP per capita or real GDP per worker

Figure 2. Association between growth of GDP per worker and growth of ideas



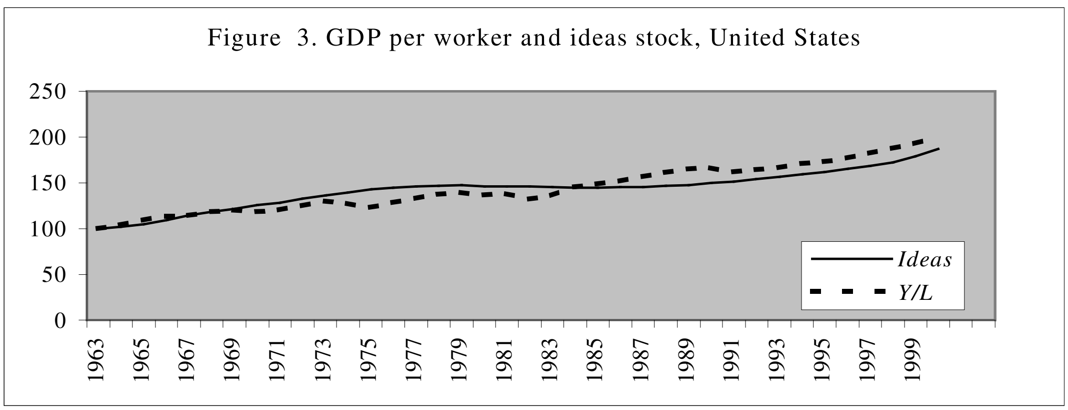
Source: the same as table 3.

Figure 2, shows the association linking the growth of ideas and the growth of GDP per worker, in 22 OECD countries (the same countries of reduced sample, plus Luxembourg). Both variable figures are calculated following the table 3 methodology and assuming a 5% obsolescence rate. As it is apparent from the graph, a large part of the association between the growth of ideas and economic growth depends on the South Korea figures. But if we exclude this country of the sample, the association keeps statistically significant: the correlation between $\dot{y}/y$ and $\dot{A}/A$, is lower than previously, but *t* statistic referent to the regression of $\dot{A}/A$ on $\dot{y}/y$ keeps maintaining the coefficient of the growth of ideas statistically significant at the 1% level.

Secondly, a possible explanation for dissimilarity between the growth rate of GDP per worker and the growth rate of ideas, besides problems associated to errors of variable measurement, should be the fact that the share of labour employed in the ideas production have increased over time. As in the long run the share of researchers in total population can't increase without limit, it is likely that the growth rate of ideas will approach the growth rate of GDP per capita.

Our results in testing the ideas production function allow us to emphasise two main findings: on the one hand, the model has more explicative power to the growth of reduced sample than to the sample-basis indicating that, in the excluded countries, the growth process should rest on a different mechanism. On the other hand, we conclude that some assumptions, where ideas driven models are usually grounded, as with $\phi = 1$, have low likelihood.

To illustrate the first finding, let's confront Portugal with the United States and the reduced sample of OECD. In figures 3, 4, and 5 the evolution of the stock of ideas index and the real per worker GDP index, from 1963 to 2000 (base year 1963), are represented[20].



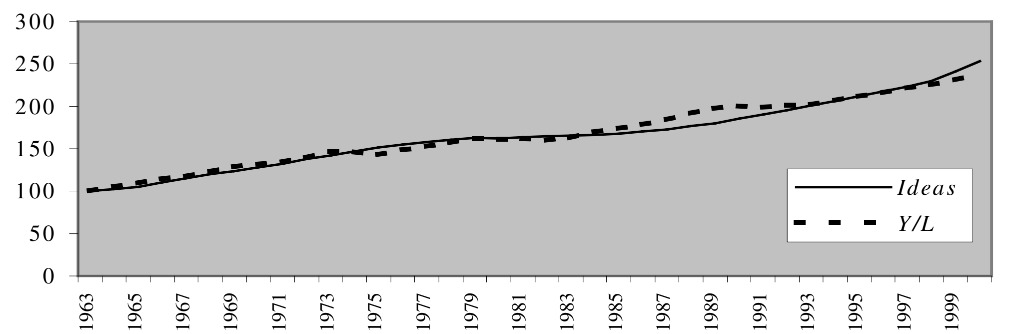
Source: Real per worker GDP — PWT 6.1; patent counts — USPTO.

Figure 3 shows that in the United States, the evolution of the stock of ideas is similar to the evolution of the real GDP per worker. Nevertheless, the growth rate of stock of ideas, averaged yearly with a 5% obsolescence rate (1,25%), was slightly inferior to the growth rate of GDP per worker (1,62%). However, the latter figure is lower than the ideas trend, where we consider 0% as obsolescence rate, indicating that the equality is possible if the obsolescence rate lies somewhere between 0% and 5%. But, more importantly, the mere observation of figure 3 shows that the equality between $\dot{y}/y$ and $\dot{A}/A$ is not unreliable in the long run, as the model tested predicts.

[20] The stock of ideas was calculated with a 5% obsolescence rate.

Furthermore, at the level of the group of countries, which compound the reduced sample, we present a dynamic behaviour of productivity and ideas, which the model predicts. To construct figure 4, we have calculated the average output per worker for a group of 21 OECD countries and the average stock of ideas for the same countries for every year from 1963 to 2000. So, figure 4 shows that the evolution of ideas was very similar to the evolution of real output per worker[21].

Figure 4. Ideas and per worker GDP evolution, in OECD



Source: Real per worker GDP — PWT 6.1; patent counts — USPTO.

But, besides similar evolution, our data show the equality of the averaged growth rates. For the whole group of countries, from 1963 to 2000, the growth trend of the stock of ideas (2,14%) was evenly equal to the growth trend of GDP per worker (2,10%)[22]. On the contrary, in Portugal, equality between $\dot{y}/y$ and $\dot{A}/A$ is out of question, as it is apparent by the observation of figure 5.

In the Portuguese economy, with the exception of the 1974-85 period, marked by instability, the increase in the output per worker seems always to anticipate ideas growth, not allowing us to think that, also in this way, the domestic creation of new ideas shall be the Portuguese engine of growth. As we have showed in other work the cause of Portuguese economic growth in the second half of the twenty century was the international technology diffusion[23].

[21] Countries included are the same of the reduced sample except Germany, and plus Luxembourg. The exclusion of Germany is owing to paucity of data in PWT 6.1, referring to real GDP per worker.
[22] Both rates are instantaneous and calculated trough the adjustment of an exponential trend line.
[23] See Pessoa 2003, chapters IV and V.

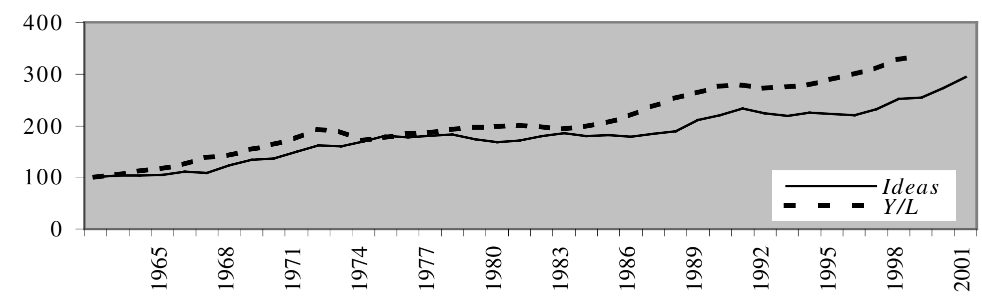


Figure 5. Ideas and per worker GDP, in Portugal

Source: Real per worker GDP — PWT 6.1; patent counts — USPTO.

With respect to the second main finding, our results contribute to more solid critiques to the ideas driven model. In effect, in the ideas driven model (Romer, 1990; Grossman and Helpman, 1991; and Aghion and Howitt, 1992) it is usually assumed that $\phi = 1$. In other words, new ideas are produced proportionally to the existing stock of ideas. Consequently, economic growth rate is proportional to the research carried out. However, if we admit such an assumption, population growth leads to per capita income acceleration. For, everything else constant, an increase in the population dimension increases the number of researchers and leads to an increase in the per capita growth rate. Several authors have criticised the model, because there was no evidence of any relationship between population size and growth rates, in cross-country data.

However, it's important to note that the ideas-driven model is meant to describe the advanced countries of the world, taken as a whole, as figure 4 shows. Being so, one can't take evidence on population growth across countries to test de model. Since there is trade between economies, the population growth rate relevant to the ideas growth model is not the resident in the country but all the people that is related to the ideas growth. In other words, there may exist international spillovers that are not translated in the estimates[24].

[24] For instance, the U. S. economy doesn't benefit only of either the ideas created in United States or of the scale of production of its internal market.

6. CONCLUSION AND POLICY IMPLICATIONS

The existence of marginal decreasing returns in each one of the factors of the ideas production function, has as main consequence that a constant growth rate of ideas depends on the constant growth of resources affected to the production of ideas, in a way that policies inducing growth of ideas production should increase the productivity level, but have no impact on the long run growth rate[25]. On the contrary, if we admit $\phi = \lambda = 1$ restrictions, the growth rate of ideas is a function of the level of effort dedicated to the production of ideas — $\dot{A}/A = \pi L_A$. Being so, policies that permanently affect the level of L_A, have permanent effects on ideas growth rate and, consequently, on the economic growth rate.

However, in medium term, the model can have a similar behaviour with ϕ=1 and with ϕ<1, if in this case the ϕ estimate lay near 1. Assuming a change, even small, in the number of researchers, for ϕ figures near of 1, a significant increase in the level of ideas productivity might result, according to $\lambda/(1-\phi)$, when a large transition period comes to the end. This upsurge would put the level of ideas on a figure nearer to that resulting of λ e ϕ both equal to 1. That is, no matter how the model *steady-state* predictions may be different, the model behaves similarly when ϕ moves toward 1.

But, if the differences are not apparent in the medium term, the actual value of ϕ has an important impact in terms of policy implications, because the ideas-driven growth depends on maintaining innovation incentives. Incentives preservation command that marginal productivity of ideas sector increases proportionally to TFP and that the producers are able of appropriate on the marginal product of their own ideas. If $\phi < 1$, the marginal productivity of ideas sector decreases over time. When this happens, the viability of the ideas sector depends on the public incentives to the production of knowledge, being in this way public intervention justified in order to induce growth positively.

[25] Constant growth rate of ideas, in the long run, depends on the growth rate of the effort dedicated to ideas production $\left(\dot{L}_A/L_A\right)$, as is the logic of equation 11.

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