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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 to generate 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

1 Introduction

A crucial economic attribute of knowledge, highlighted in recent models of endogenous growth, is that ideas are both non-rivalrous 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

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public goods. The public-good nature of knowledge, that is, the nonrivalrous nature of knowledge 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, the productivity of the ideas sector must increase proportionally with the stock of ideas already discovered. The 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 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 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 researchers and TFP growth rate has led some to question the viability of ideas-driven growth for the long run (Jones, 2001).

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 generate 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

[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.

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 also compute the elasticity of new ideas with respect to the number of researchers.

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, presents the theory that supports the model used in our empirical tests and mentions some other attempts to estimate a production function for ideas. In Section 3, we explain the generation of our stocks of commercially used ideas and the data considered. The empirical findings about spillovers are depicted in Section 4. Section 5 compares the evolution of ideas with the economic growth. Section 6 compares our results with the results of other papers. Finally, Section 7 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 dynamic 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.[2]

In fact, in addressing the problem of limits to human capabilities, Paul Romer (1990) emphasises the distinction between human capital – the skills and abilities that are embodied in individual humans –, and ideas, which are disembodied

[2] 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.

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 to this, the mathematical representation of the generation of new ideas, in Romer’s model, is:

$$\dot{A} = \pi L_A A. \tag{1}$$

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, A represents the stock of ideas existing until time t, and $\pi > 0$ is a constant.[3]

As it is apparent from equation (1), Romer assumes that the productivity of the research is directly proportional to the extant stock of knowledge. 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 that there is an evenly distributed and infinite universe of potential ideas waiting to be discovered. So, a given amount of research effort will produce a predictable number of new ideas.[4]

Jones (1995, 1998) criticises some of the key assumptions underpinning 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[5]:

$$\dot{A} = \pi L_A^{\lambda} A^{\phi} \tag{2}$$

This function, like function (1), turns the rate of technological change endogenous in two distinct ways. First, the share of the economy devoted to the ideas sector is a function of the R&D labor market; allocation to the ideas sector depends on R&D productivity and on the private economic return to new ideas. Second, the productivity of the creation of new ideas is sensitive to the stock of ideas discovered in the past. These two distinct ways gave rise to two strings of empirical discussion. One string (Stokey, 1995; Jones and Williams, 2000) aims at determining the factors that tend to make the aggregate rate of R&D in decentralized equilibrium too low or too high compared with the social optimum. The other string (Caballero and Jaffe, 1993; Porter and Stern, 2000) aims at clarifying the dimension of externalities from

[3] 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. On the empirical determinants of π, see Stern, Porter, and Furnam (2000).

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

[5] Equation (2) can also be seen as a more general form of Romer (1990)’s equation, if we are assuming $\lambda = 1$ and $\phi = 1$.

the existing stock of ideas to the production of new ideas. Our work is focused on this second string.

In the ideas production function (2), two kinds of externalities may be represented. One is related to the R&D workers (λ) and the other is 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 the debate on ideas driven-growth. But the estimation of those two parameters is also important to determine the rate of technological progress.

Assuming that the production function of ideas takes the form (2), the rate of technological progress, as Jones (1998) shows, is given by the formula:

$$\frac{\dot{A}}{A} = \frac{\lambda}{1-\phi}\frac{\dot{L}_A}{L_A}, \quad \text{or} \quad \frac{\dot{A}}{A} = \frac{\lambda n}{1-\phi} \tag{3}$$

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 $\lambda = 1$ and $\phi = 0$, the ideas production function takes the form $\dot{A} = \pi L_A$ and researchers productivity is the constant π, 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 $\lambda = 1$ and $\phi = 0$, the economy generates a constant number of new ideas in every period, meaning that the growth rate of the stock of ideas decreases over time, though technical progress doesn't cease. 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.[6]

Of course, besides the distortions associated to λ and ϕ, other distortions exist related to the R&D production function as has been discussed in Stokey (1995)

[6] 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.

and Jones and Williams (2000). These two studies also discuss a third distortion associated with creative destruction in the research process, which had previously been highlighted by Grossman and Helpman (1991) and Aghion and Howitt (1992). In fact, creative destruction can provide an incentive for overinvestment in research since some innovators earn rents on ideas that are not entirely new. However we must distinguish between creative destruction (new ideas make the products that embody old ideas less valuable) and knowledge obsolescence (old ideas are made obsolete by the emergence of newer ideas). Our paper takes knowledge obsolescence into account considering a rate of substitution of old ideas by the new ones in the stock of ideas, A.

Because of the above-mentioned reasons, assessing if function (2) 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 economic growth. Additionally, the parameters that we estimate in this paper are very important because they can help validating the results of the calibration of some models, such as the ones developed by Stokey (1995) and Jones and Williams (2000).[7]

As a matter of fact, Stokey (1995) leaves λ as a free parameter in her calibration because she argues that the empirical literature does not provide much guidance in choosing a value for λ. Jones and Williams (2000) argue that a lower bound for λ of about 0.5 is plausible, but they end presenting results for values of λ between 0.25 and 1.00 in their calibration. On the other hand, in Jones and Williams's (2000) paper, the value of ϕ depends on the particular value of λ. So, the estimation of the parameters of equation (2) can help finding a more accurate form of calibrating R&D models, besides being helpful in the characterization of OECD economic growth.

3 Data and the stock of ideas

In order to assess the empirical evidence, we'll start with equation (2), the production function of ideas built by Jones (1995). Taking natural logs, we have:

$$\ln \dot{A} = \ln \pi + \lambda \ln L_A + \phi \ln A \tag{4}$$

Equation (4) 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 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, as well as the resolution of technical problems at 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),

[7] Although Stokey (1995) uses a different framework (inspired in Grossman and Helpman, 1991) and examines the distortions of the function for R&D in a quality ladders model, she share some distortions with Jones and Williams (2000) who develop a varieties model inspired in Romer (1990), as our present empirical work.

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. In order to generate the stock of ideas (A) and the number of new economically useful ideas $(\dot{A})$, the most obvious indicators are R&D outlays and 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 build the proxies of $\dot{A}$ and A. The main reasons to have chosen patent counts instead of BERD are the following:

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 for the development of this product or idea, thus indicating 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. Moreover, 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 the 30 OECD countries, in 2002, and patents granted in the United States to inventors residents in each one of those countries. Both variables are calculated in per capita terms and are presented in logarithmic scale.[8]

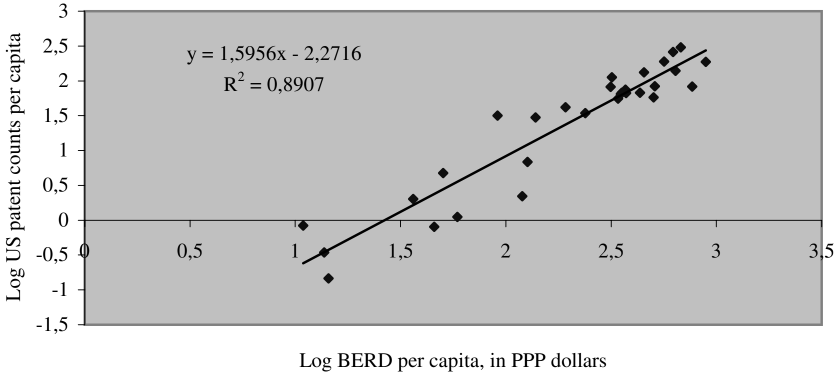

Fig. 1. Association between BERD and patent counts. *Sources.* OCDE (MSTI data base), and USPTO

It is apparent in Figure 1 that there is a high positive correlation between the two variables (correlation coefficient = 0.944). But, besides high correlation, there is some evidence that shows that the correlation between total factor productivity (TFP) and patent counts is higher than between TFP and BERD (see Griliches, 1989, Fig. 6; Griliches, 1990, Fig. 10).

[8] 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 between 2000 and 2002.

Patent use is subject to several critiques. 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 intellectual property rights, in the same way as it could reflect the existence of cyclical waves in the realisation of important ideas.[9] But the most emphasised critique observes that not all inventions are patentable, and not all inventions are patented. Besides, the inventions that are patented differ greatly in quality and in the size of inventive output associated with them. In relationship to these critiques 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 to allow the use of the law of large numbers.

The use of patent counts to draw the stock of economically 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 an 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 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 residents in the OECD countries.[10] Why did we choose the use of US patents and not patents granted by the authorities of OECD countries to their residents?

In spite of the efforts made in recent times by international organizations like WTO, namely with the TRIPS (Trade-Related Aspects of Intellectual Property Rights) agreement, there are important differences in the industrial property systems of the different countries, and the harmonization of Intellectual Property Rights (IPR) is far from complete. Because our main purpose is to build a stock of ideas, which can be the basis for testing the production function of economically useful knowledge to the OECD as a whole, we need numbers of patents that satisfy a uniform criterion in order to allow an unbiased aggregation, in terms of quality and value.

Although there is a positive correlation (coefficient of correlation 0.84 for the 2000–2002 period) between the number of patents granted by national industrial property authorities of each OECD country to their own residents and the number of patents granted by USPTO to the residents of the same OECD countries, it is clear

[9] It is convenient to distinguish 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.

[10] In calculating the stock of ideas we only use 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. Since the distribution of total patents by different types varies across countries, we need a weighing criterion to build a stock of ideas comparable across countries. In the absence of such a criterion, we decided to use only utility patents, which correspond to the larger percentage in the total number of patents.

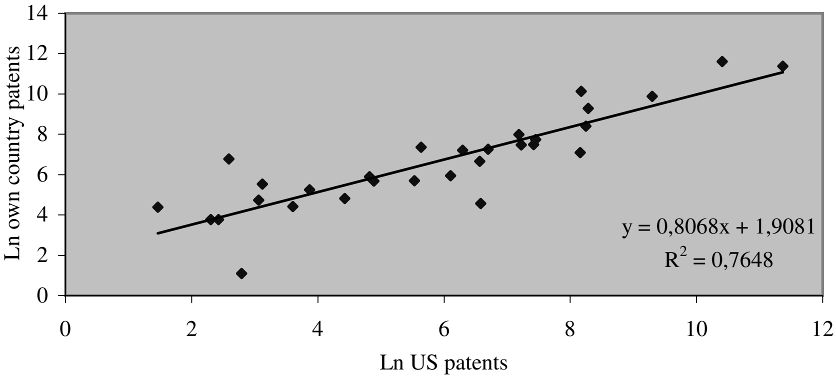

Fig. 2. Own country patents and US patents. *Source.* Own country patents – WIPO; US patents – USPTO

from Figure 2 that the ratio between the number of patents granted by national authorities and the number of patents granted by USPTO greatly differs across OECD countries, ranging from 0.13 in Finland to 65.6 in Poland (see Table 7 in Appendix B). This variability is largely associated with differences in the procedures and resources of the various Intellectual Property Offices implying, consequently, also differences in the average "quality" of a granted patent across countries.

On the other hand, a patent in a specific country grants protection in two ways: it protects the inventor from imitators producing in that country and it protects the inventor from foreign imitators selling in that country. So, the larger the economic dimension of the country where the invention is protected, the higher the economic value of the patent could be. Accordingly, other underlying reasons for using US patents are the dimension of the US market and the US location at the technological frontier.

4 Estimates for spillovers

In the following empirical tests we'll consider two samples. The first one (base sample) comprises 27 countries of the OECD. In this sample we have considered every OECD country except both Luxembourg, because of its paucity of data about researchers, and the Czech Republic and Slovakia because data about patent counts there don't allow us to build a stock of ideas according to the same criteria used for the other countries, that is, they don't allow us to discriminate patents granted to residents in each country.[11]

The second sample (reduced sample) contains the countries included in the base sample minus Poland, Portugal, Turkey, Greece, Mexico and Hungary. The exclusion of these countries is justified for two reasons. First, because they are less developed than the other OECD countries, and so it is likely that the growth pattern won't be the same as in the other (more developed) countries. Secondly, the

[11] 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.

Table 1. Ideas production function estimation results for two samples of OECD, 1998

Obsole-scence rate	$d = 0\%$		$d = 5\%$		$d = 10\%$		$d = 15\%$	
N	27	21	27	21	27	21	27	21
Constant	−8.246*	−4.771*	−2.289**	−3.677*	−1.602**	−2.880*	−1.167+	−2.292*
	(−3.90)	(−5.484)	(−2.57)	(−4.338)	(−2.28)	(−3.853)	(−1.96)	(−3.501)
λ	1.122**	0.663*	−0.005+	0.447**	−0.026+	0.331**	−0.028+	0.262**
	(2.71)	(3.122)	(−0.04)	(2.288)	(−0.24)	(2.090)	(−0.31)	(2.017)
ϕ	0.261+	0.467*	1.012*	0.642*	1.022*	0.732*	1.021*	0.786*
	(0.96)	(3.282)	(12.70)	(4.781)	(15.89)	(6.747)	(17.62)	(8.913)
R^2	0.72	0.97	0.97	0.98	0.98	0.99	0.98	0.99
Ramsey's reset test	F_1 =0.06 F_2 =0.05	F_1 =0.29 F_2 =0.39	F_1 =0.48 F_2 =0.24	F_1 =0.09 F_2 =0.21	F_1 =0.33 F_2 =0.18	F_1 =0.02 F_2 =0.09	F_1 =0.28 F_2 =0.18	F_1 =0.01 F_2 =0.03

Source. Researchers – OCDE, MSTI database; Patent counts – USPTO.
Notes. t statistics (White heteroskedasticity-consistent) in parentheses, * 1% signification level; ** 5% signification level; + Not significant. $F_i$is F-statistic for $_i$ fitted terms.

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.[12] Besides, the low level and the negative growth rate of patent counts may contribute to extra measurement errors in the calculation of the stock of ideas.

In this section we'll proceed in two stages. Firstly, we'll test the plausibility of the value of the obsolescence rate, using cross-section data for 1998. Secondly, we'll aim at estimating the parameters of the ideas production function using panel data for the 1980–2002 period. Empirical results of the regressions are presented in two tables. Table 1 shows the estimates for the two samples of OECD countries using cross-section data; Table 2 presents the estimates for the panel data. In Table 1 the results are distributed in four columns, according to the obsolescence rate, d, used in the calculation of the stock of ideas.[13]

A quick glance at Table 1 shows that in every case the F value associated to the Ramsey's reset test is highly insignificant pointing to the non-existence of specification errors. Table 1 also shows that the base sample faces more problems of statistical significance, measured by *t-statistic*, than the reduced sample. With respect to the base sample estimates, we can distinguish 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

[12] 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, the correlation coefficient of the 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.

[13] The stock of ideas is calculated according the methodology presented in Appendix A.

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, it 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), in the base sample, loses its statistical significance. Additionally, in this sample, 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 constant number of researchers, the growth rate of ideas should increase given the high elasticity of the stock of ideas ($\phi > 1$). 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 results seem counterfactual: in the last forty years, at least, per capita growth of income coexisted with the growth of researchers. This counterfactual result, together with the loss of statistical significance, questions the appropriateness of the model to the base sample of the OECD when new ideas substitute old ones.

Let's analyse now the reduced sample. 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 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. On the other hand, although the estimates of λ and ϕ are sensitive, as expected, to the obsolescence rate of the ideas stock its signs are always positive and its values are not much different from one obsolescence rate to another.

The estimates presented in Table 1 were obtained from a cross-section for the year of 1998, but this year could not be significant. On the other hand, the extreme simplification of the model can produce biased estimates. In order to minimise these two possible drawbacks we'll use a data panel for the two OECD samples in the 1980–2002 period.[14] As it is likely that residuals may violate some assumptions of the Classical Linear Regression Model, and the tests made to detect autocorrelation and heteroskedasticity were not conclusive, we'll present, in Table 2, the estimated results for two regression techniques: GLS, with cross-section weights, if the residuals are contemporaneously uncorrelated but cross-section heteroskedastic, and SUR (seemingly unrelated regression), if the residuals are both cross-section heteroskedastic and contemporaneously correlated. In the two techniques, we'll present both estimates based on a common intercept and on a fixed effects model.[15]

[14] We report only the panel estimation based on the stock of ideas calculated with a 5 percent obsolescence rate. The estimates based on stocks of ideas with 10 percent and 15 percent obsolescence rate are also statistically significant.

[15] We have also estimated the model using system OLS. System OLS is appropriate when the residuals are contemporaneously uncorrelated, and time-period and cross-section homoskedastic. The results of estimation following system OLS, not reported on Table 2, are not very different from the ones of GLS estimation.

Table 2. Estimation results from *panel data*, for OECD, 1980–2002 (d=5%)

	Pooled				Fixed effects a)			
	GLS (cross-section weights)		SUR		GLS (cross-section weights)		SUR	
N	27	21	27	21	27	21	27	21
Constant	−3.190*	−3.668*	−3.252*	−3.825*				
	(−39.93)	(−39.43)	(−48.40)	(−51.39)				
λ	0.155*	0.355*	0.126*	0.379*	0.657*	0.556*	0.744*	0.596*
	(10.59)	(18.53)	(11.25)	(31.06)	(25.81)	(22.02)	(38.60)	(29.22)
ϕ	0.894*	0.719*	0.937*	0.708*	0.736*	0.802*	0.725*	0.799*
	(72.78)	(46.52)	(120.15)	(80.25)	(38.72)	(37.59)	(60.32)	(54.43)
T	23	23	23	23	23	23	23	23
Obs.	401	326	401	326	401	326	401	326
R^2	0.99	0.99	0.95	0.97	0.99	0.99	0.98	0.98
Wald test (Chi-square)	49.92	90.11	137.58	217.47	447.08	321.29	724.48	384.11

Source. Researchers – OCDE, MSTI database; Patent counts – USPTO.
Notes. *t* statistics (White heteroskedasticity-consistent) in parentheses, * 1% signification level; ** 5% signification level; + Not significant. a) Country fixed effects, not reported owing to space restrictions, are available from the author upon request.

We’ll also show the result of the Wald test to check the restriction that the function has constant returns to scale.

For any estimation technique, the fit is very good: the coefficients are statistically significant at the 1% level and the R^2 is very high. With the estimation results on Table 2 we can’t say that the model has more explicative power for the reduced sample than for the base sample, as was appeared in Table 1. Particularly in the fixed effects model *t-statistic* is marginally higher in the base sample than in the reduced sample.

For whatever technique, the estimates of λ and ϕ are positive and less than 1. This means that in the ideas production function each factor, L_A and A, has marginal decreasing returns. So, both the increase in the number of researchers, and the increase in the 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. So, 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 the 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.

Obtained results also show that the production of ideas is generated at increasing returns to scale: simultaneous increase of L_A and A generates a more than proportional increase in the number of new ideas, $\dot{A}$. Additionally, the Wald coefficient test of the restriction that $\lambda + \phi = 1$, reported on the bottom line of Table 2, shows that the probability of constant returns to scale is zero

To conclude this section we’ll make some comments on the high values of R^2, varying between 0.95 and 0.99. With only two explanatory variables and such high R^2 values, it can be argued that the estimation of the ideas production function on

Table 2 seems strange. However, two facts must be considered. First, these high R^2 values are identical to the figures found in Porter and Stern's (2000) paper, which has used different samples and different methods in order to calculate the stock of ideas. Secondly, possible reasons for this extraordinary fit can result from explaining the flow of new ideas partly with a variable that is very closely related to the stock of extant ideas. But, if ideas are cumulative, theory constricts us to formalise both variables (the flow of new ideas and the stock of extant ideas) as closely related.

5 Ideas growth and economic growth

The ideas-driven growth 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, per capita output and capital/labour *ratio* must increase at the same rate as the stock of ideas. This equality deserves an additional test. Some authors (v. g., Porter and Stern, 2000) estimate an equation that relates patents to total factor productivity (TFP). However, in the context of an endogenous growth model the technique to calculate TFP is subject to several caveats, which create additional complications (see Barro, 1998). In order to avoid additional measurement errors, which such complications may induce, we prefer to use in the present paper a less sophisticated approach simply comparing the evolution of ideas with the evolution of GDP per worker.

On Table 3 we report two types of growth rates of ideas in OECD countries:[16] the actual growth rate in 1998 and the long run trend. In the former we have used the average of the utility patent counts granted by USPTO from 1995 to 1998 as $\dot{A}$ measure and we have employed as denominator the measure of the stock of ideas in 1998, calculated as previously (equations A1 and A2 in Appendix A), admitting obsolescence rates of 0% and 5%.[17]

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 and 1962–2000 periods, respectively, with trends instantaneous rates, which were calculated by us with PWT 6.1 (Heston *et al.*, 2002) data, using the OLS method.

Table 3 shows that at the individual country level the relationship between ideas growth and economic growth is very different from country to country, but the growth rate of ideas in a specific country is usually higher than growth trends of GDP per capita and GDP per worker, for the same country. Nevertheless Table 3 also shows that the obsolescence rate is crucial to determine the growth rate of ideas.

[16] Czech Republic and Slovakia are excluded due to paucity of data.

[17] The use of averaged count of patents is due to the need of taking the bureaucratic cycles in the grant of patents into account. 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 for 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
OECD:						
N=21		2.14			2.10	
N=27		2.42			a)	

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; a) Not computed owing to paucity of data related to Poland and Hungary.

Without new research 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.

On the other hand, in terms of large trends, the 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 on 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, as it is apparent from Figure 3.

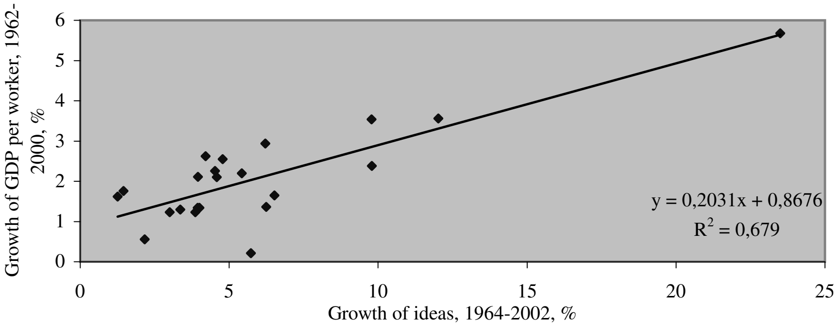

Fig. 3. Growth of GDP per worker and growth of ideas. *Source.* The same as Table 3

Figure 3 shows the association linking the growth of ideas and the growth of GDP per worker, in 22 OECD countries (the same countries of the reduced sample, plus Luxembourg). Both variable figures are calculated following 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 from 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 1% level.

Secondly, Table 3 shows that the growth rate of ideas does not correspond to either the growth rate of GDP per capita or the growth rate of GDP per worker in a specific OECD country. This fact is not unexpected because a country benefits not only from ideas created domestically but also from ideas produced abroad. Our empirical model is not directed towards the explanation of the behaviour of a specific country, but only to find estimates of the ideas production function in the OECD as a whole. Besides, the ideas-driven growth model should be appropriate to the “advanced countries of the world taken as a whole” (Jones, 1998, p. 95).

According to the above-mentioned quotation, the group of countries that compound the reduced sample, taken as a whole present a dynamic behaviour of productivity and ideas, as the model predicts. To generate Figure 4, we have calculated the average output per worker for a group of 21 OECD countries and the total stock of ideas for the same group of 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.[18]

But, besides the similar evolution of ideas apparent from Figure 4, 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 total stock of ideas (2.14%) was evenly equal to the growth trend of GDP per worker (2.10%).[19]

[18] Countries included are the same of the reduced sample except Germany, and plus Luxembourg. The exclusion of Germany is due to paucity of data in PWT 6.1, referring to real GDP per worker.

[19] Both rates are instantaneous and calculated through the adjustment of an exponential trend line.

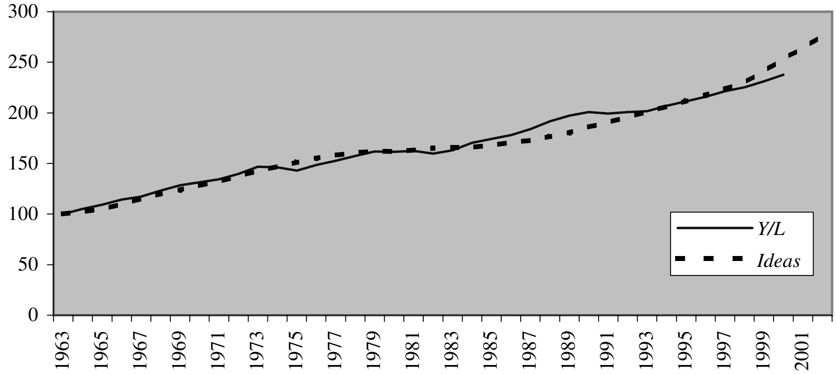

Fig. 4. Ideas and GDP per worker evolution, in OECD. *Source.* Real GDP per worker – PWT 6.1; patent counts – USPTO

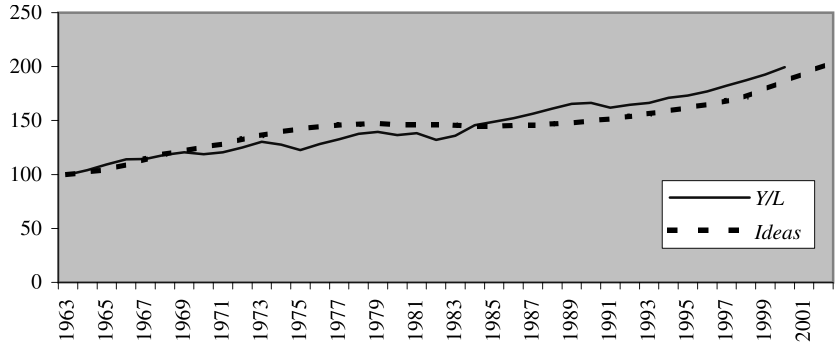

Fig. 5. Ideas stock and GDP per worker, in USA. *Source.* Real GDP per worker – PWT 6.1; patent counts – USPTO

Of course we see different patterns at country level. We see countries with a close link between ideas growth and productivity growth and countries where those trends are divergent. To illustrate this outcome, let's confront Portugal with the United States. In Figures 5 and 6 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]

Figure 5 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 the stock of ideas, averaged yearly with a 5% obsolescence rate (1.25%), is slightly inferior to the growth rate of GDP per worker (1.62%). However, the latter figure is lower than the ideas trend when 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 5 shows that the equality between $\dot{y}/y$ and $\dot{A}/A$ is attainable in the long run, as the model tested predicts.

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

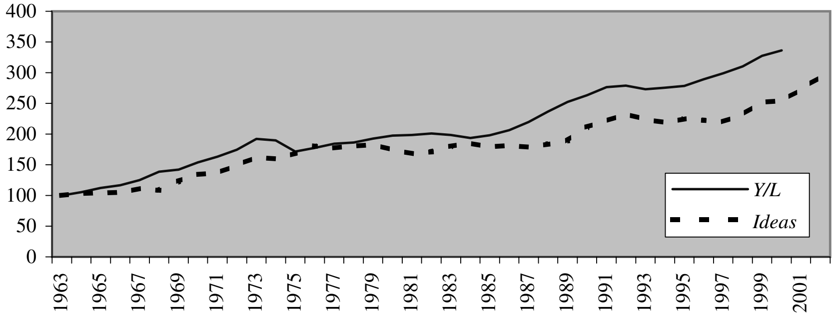

Fig. 6. Ideas stock and GDP per worker, in Portugal. *Source.* Real GDP per worker – PWT 6.1; patent counts – USPTO

On the contrary, in Portugal the equality between $\dot{y}/y$ and $\dot{A}/A$ is out of question, as it is apparent from the observation of Figure 6. With the exception of the 1974–1985 period, marked by instability, in the Portuguese economy, the increase in the output per worker always seems to anticipate ideas growth, preventing us to think that the domestic creation of new ideas will be the Portuguese engine of growth.

Our empirical test, in showing that the number of new ideas is less than proportional to the stock of existing ideas $(\phi < 1)$, illustrates the fact that the growth rate of ideas can only rise if there is an increase in the 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. As mentioned in Section 2, in such a situation the rate of technological progress in the long run would be proportional to the growth rate of the number of researchers, as illustrated by equation 3. So, with the estimates found we can simulate the rate of technological progress for the OECD as a whole for each sample. However, with the available data it is not possible to calculate the growth rate of the number of researchers; consequently, we'll use l (labour force growth rate) and n (population growth rate) as *proxies* of this rate.

Table 4. Predicted steady-state rate of technological progress for OECD as a whole

Sample	l	n	Pooled		Fixed effects	
			GLS	SUR	GLS	SUR
Reduced (21)	1.01		1.27	1.31	2.83	2.99
		0.64	0.81	0.84	1.81	1.91
Base (27)	1.17		1.71	2.34	2.92	3.17
		0.79	1.15	1.58	1.96	2.13

Source. Calculations based in Table 2 estimates.
Notes. l and n are the growth rates of, respectively, labour force and population, from 1980 to 2002.

Although we bear in mind that "the long run growth rate" is a theoretical abstraction, never observable in practice, our estimates give an image that should not be considered implausible. Table 4 shows l and n, as *proxies* of the growth rate of researchers between 1980 and 2002, and the predicted growth rate of ideas according to the equation $\dot{A}/A = \lambda(\dot{L}_A/L_A)/(1-\phi)$. If we accept l as a good *proxy* of the growth rate of researchers, our estimates predict a long run growth rate of technological change between 1.27 and 2.99 for the reduced sample.

6 Empirical literature

As already mentioned in Section 2, empirical literature on the R&D as source of growth has followed two trails: One aims at determining the factors that tend to make the aggregate rate of R&D in decentralized equilibrium too low or too high compared with the social optimum; the other intends to shed light on the dimension of externalities from the existing stock of ideas to the production of new ideas.

The former trail is inserted in a field where there is a lot of microeconomic evidence. Early studies found private rates of return to R&D ranging from 30 to 50 percent (Hall, 1995). Other studies show that social returns are even higher (Griliches, 1979, 1992).[21] However some doubts arise around the results of those empirical studies as they ignore some negative externalities, such as the "business stealing" effect, therefore overstating the social returns to research. On the other hand, it can be argued that it is possible that such distortions as creative destruction and monopoly power affect the share of R&D in output, but do not affect the relationship between the social rate of return and the R&D share. For this reason regressions based on the R&D share may approximate the social rate of return reasonably, and perhaps even understate it. In this respect, Jones and Williams (1998) found that optimal R&D investment is at least four times greater than actual spending. However, the same authors recognize the econometric difficulties associated to the empirical estimates of the return to R&D and the necessity of an independent check on the previous estimated results (Jones and Williams, 2000).

Due to the empirical difficulties in estimating R&D models, Jones and Williams (2000) follow Stokey (1995) using a calibrated endogenous growth model to examine the issue of over and under-investment in R&D. In the calibration of Jones and Williams (2000) the value of ϕ is partly determined by the value chosen for λ and is subject to the restriction that the growth rate of ideas is not increasing over time. In our estimation we don't make any restriction to the growth rate of ideas, but we have obtained panel estimates that, in general,[22] lie inside the boundaries used by Jones and Williams (2000), as the comparison between Table 2 and Table 5 shows.

The calibration exercises don't avoid the necessity of estimating some parameters of the functions. On the contrary, if the calibration of the models is not based on accurate estimates, their results are highly disputable. So, there is always the necessity of estimating some parameters of production functions with econometric techniques. Previous attempts to estimate a production function for ideas include Griliches (1979, 1992), Caballero and Jaffe (1993), Eaton and Kortum (1996) and

[21] See Table 1 in Jones and Williams (1998) for a review of studies that estimate social rates of return in R&D.

[22] The estimates obtained from the pooled estimation for the base sample are the only exception.

Table 5. Values of λ and ϕ used in Jones and Williams's (2000) calibration

λ	ϕ
0.25	0.8 64
0.50	0.729
0.75	0.593
1.00	0.457

Source. Table 2 in Jones and Williams (2000).

Porter and Stern (2000) but the methodology employed in each study is very different from one study to the other, which complicates the comparison between the results of all the above-mentioned papers. The two most proximate studies are the last paper mentioned and our own but, in spite of the methodological proximity there are important differences in respect to sample, results and the basic conclusion of both papers, as it is summarized in Table 6.

Table 6. Confronting alternative estimations

	This study	Porter and Stern (2000)
Obsolescence of ideas	Considered in the calculation of the ideas stock	Not considered
Sample	21 OECD countries 27 OECD countries	16 OECD countries
Time span	1980–2002 for parameters estimates 1963–2002 for confronting ideas growth and economic growth	1973–1993
Results	Base sample: $0.126 \leq \lambda \leq 0.744$ $0.725 \leq \phi \leq 0.937$ Reduced sample $0.355 \leq \lambda \leq 0.596$ $0.708 \leq \phi \leq 0.802$	$0.20 \leq \lambda \leq 0.85$ $0.84 \leq \phi \leq 1.19$
Main conclusion	Support Jones (1995)'s model	Support Romer (1990)'s model

7 Concluding remarks

We have estimated the parameters of an ideas production function, following the model built by Jones (1995). Using U. S. patents granted to residents in OECD countries we have built the stock of commercially used ideas and, based on it, we have found 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. So, our estimates of λ and ϕ, positive and less than 1, support Jones's (1995) model against the restrictive assumptions of Romer's (1990) model.

On the other hand, we provide evidence of the association between ideas growth and economic growth, for the OECD as a whole, in the long run. At the same time we predict the steady-state rate of technological progress for the OECD as a whole in the long run. These findings also allow us to dismiss some criticisms, which contest the ideas-driven growth model based on comparisons between economic growth and research growth rates at the country level.

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 the growth of ideas production should increase the productivity level, but have no impact on the long run growth rate. Constant growth rate of ideas, in the long run, depends on the growth rate of the effort dedicated to ideas production.

Appendix A. Calculation of the stock of ideas

The net stock of ideas (A) is calculated from patent counts (P) granted by USPTO based on the perpetual inventory model:

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

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:

$$A_0 = {}^{P_0}\!/_{g + d} \tag{A.2}$$

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 the 1963–2002 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 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 the obsolescence rate, we have calculated the stock of ideas in four hypotheses: $d = 0\%, d = 5\%, d = 10\%$ and $d = 15\%$.

Appendix B. Number of patents granted in each country and in the US

Table 7. Number of patents granted in each country and in the US, average 2000–2002

	Patents granted in the US (1)	Patents granted by own country authority (2)	Ratio (2)/(1)
Australia	813	1415	1.74
Austria	541	1349	2.49
Belgium	711	783	1.10
Canada	3485	1193	0.34
Czech Republic	23	251	11.09
Denmark	447	381	0.85
Finland	720	96	0.13
France	3965	10737	2.71
Germany	10924	19593	1.79
Greece	21	114	5.33
Hungary	48	189	3.94
Iceland	16	3	0.18
Ireland	133	294	2.21
Italy	1725	2298	1.33
Japan	33126	110053	3.32
Luxembourg	37	83	2.27
Mexico	84	123	1.47
Netherlands	1321	2929	2.22
New Zealand	124	361	2.92
Norway	252	298	1.19
Poland	13	875	65.60
Portugal	11	44	3.85
Republic of Korea	3546	24984	7.05
Slovakia	4	80	18.46
Spain	281	1564	5.57
Sweden	1664	1795	1.08
Switzerland	1369	1746	1.28
Turkey	10	44	4.37
United Kingdom	3823	4452	1.16
United States of America	86551	86551	1.00

Sources: WIPO for patents granted by own country patent authority and USPTO for US patents.

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