

IMF Working Paper

The Impact of Research and Development Tax Incentives on Colombia's Manufacturing Sector: What Difference Do They Make?

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Research Department

**The Impact of Research and Development Tax Incentives on Colombia's
Manufacturing Sector: What Difference Do They Make?**

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Abstract

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The views expressed in this are those of the author and do not necessarily represent those of the IMF or IMF policy. describe research in progress by the author and are published to elicit comments and to further debate.

Do tax incentives for science and technology stimulate additional investment? We use detailed data on applications and acceptances for R&D tax incentives, a special survey, and for the first time, the science and technology module from the 2000-2002 *Survey of Manufacturers* database in Colombia to analyze this question. We estimate the effect of the R&D tax deduction instituted in Colombia using Zellner's *Seemingly Unrelated Regressions* method, and find that the elasticity of demand of R&D investment in manufacturing is quite high in Colombia compared to other countries, particularly for smaller firms, but that the direct benefit from existing policies is minimal. Overall, the results of the paper suggest that there is a great potential for such incentives to promote R&D investment in Colombia, but in their current form, they fail to target those firms that could benefit the most.

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I. INTRODUCTION

Despite numerous economic studies showing evidence of the benefits of promoting research and development for economic development, many emerging markets still lag behind in terms of science education and fostering home-grown technology. Much of the technological advances still occur through the adoption of technology created elsewhere. As with Colombia, the public agency in charge of promoting science and technology is typically small and not given a central role in the development of the country.

This paper analyzes the effects of a very small but potentially central part of Colombia's science and technology promotion policies: R&D tax deductions. Such tax incentives constitute the crucial link necessary to foster a generation of innovative and technology-minded private-sector entrepreneurs, something sorely lacking in many developing countries, but well-understood by the decision-makers of Colciencias, the Colombian science and technology promotion agency. To understand the context under which these incentives operate, it is necessary to consider not only what is done in other countries and how the policies operate in Colombia, but also, the effects of R&D expenditures in general. The main contribution of the paper is thus to estimate the effectiveness of R&D incentives in Colombia as they pertain to the manufacturing sector, in particular, the production and price-demand elasticities of R&D, the substitution among factors, and how much additional investment is created, if any, as a result of current tax incentives.

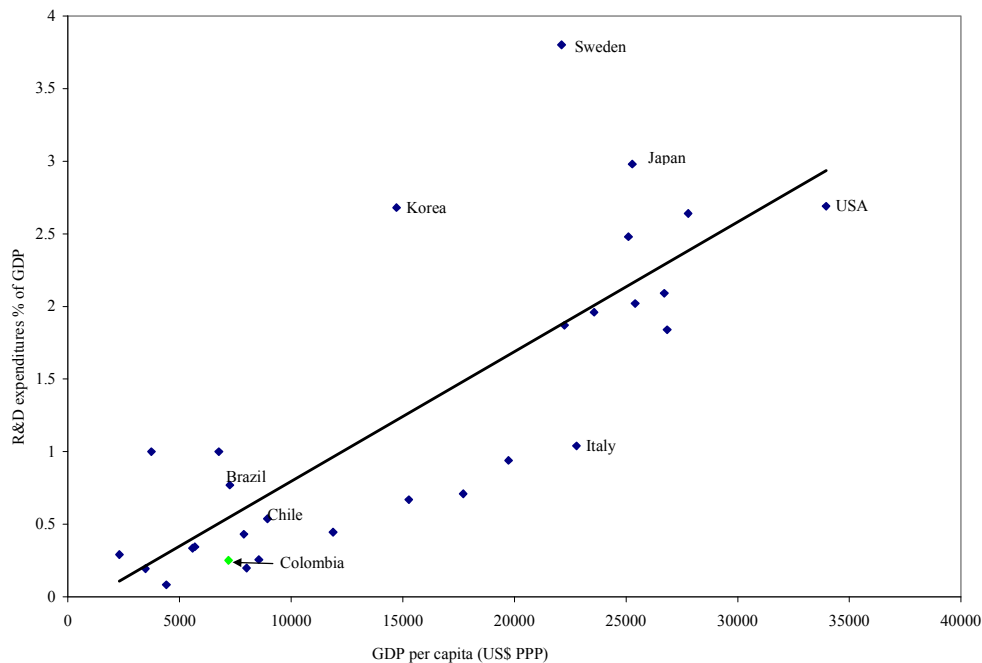
The paper finds that Colombia's tax incentives program, while efficiently and appropriately run, is too small to make a substantial dent in the technological development of industry. Survey results suggest that Colombian firms understand the importance R&D can have on their growth and competitiveness, but that they do not know much about the options available. The high estimated elasticities suggest that manufacturing firms—particularly small and medium-sized ones (SMEs)—are likely to increase their rate of R&D investment by 1.43 percent for a given 1 percentage point reduction in the effective price of R&D (with the number being 2.0 for SMEs). Moreover, the ensuing productivity is likely to lead to more R&D investment. However, current policies are not well-targeted or generous enough to affect those prices. The paper suggests that a more generous system—such as tax credits proportional to the amount of the firms' R&D investment—could go a long way towards improving the effectiveness of the tax incentives program.

The paper is divided as follows. Section II surveys the literature and the general results from similar studies in other countries. Section III looks at the system of R&D tax incentives in Colombia and firms' attitudes towards them, as well as a firm survey of technological adoption. Section IV estimates elasticities and parameters using the establishment-level panel data from the manufacturing sector. Section V concludes.

II. THE ECONOMICS OF R&D TAX INCENTIVES AND RESULTS FROM OTHER STUDIES

Modern economic literature has developed a strong theoretical framework and relatively broad empirical findings which suggest that the development of R&D can enhance economic growth by pushing the technological frontier and by creating economies of scale and scope. (Solow and Swan (1956), Romer (1986), and Aghion and Horwitz (1992, 1998)). The basic premise is that when R&D is performed by an individual or firm, a positive externality is created which benefits all of society, which the firm cannot appropriate for itself. Therefore, it does not receive the full financial benefits from the effort invested. Consequently, without some form of government intervention or financial incentive, the private sector will not invest the socially optimal amount in R&D. The implication is that governments should contribute to greater R&D investment to correct the externality of private firms by offering, say, tax incentives.

Figure 1. Relationship Between R&D Expenditures and Per-capita Incomes, 2000



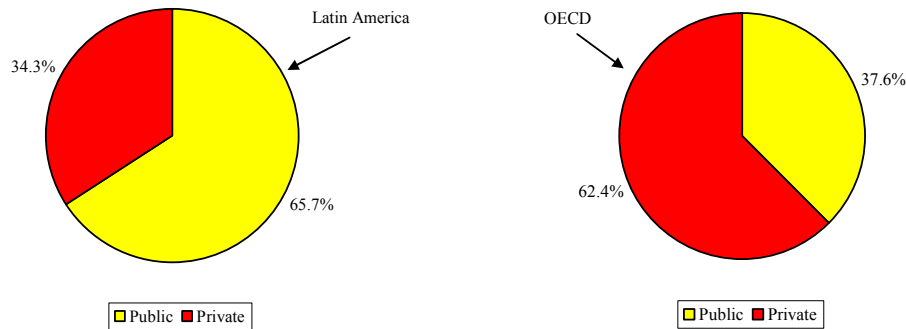
Source: World Bank, World Development Indicators

A useful point of departure is to compare expenditures in R&D as a percentage of GDP to the level of development, or income per capita (Figure 1). Not surprisingly, the relationship is clearly positive. Various growth studies find that the direction of causality runs from technological change to economic growth. The former is a necessary condition for the latter, so it is not surprising that countries that have already experienced their growth spur have relatively higher R&D expenditures to GDP (Barro and Sala-i-Martin(2003)).

What seems to be more interesting is that as countries develop, more and more of their R&D tends to be financed by the private sector relative to the public sector. Latin

American R&D (including Colombian) is still heavily dominated by the state, a point highlighted by Hansen et, al (2002) and by Nolan and Pack(2003) in comparing R&D investment in Latin America to OECD and Asian countries, respectively (Figure 2). This could reflect the greater need of firms in more advanced countries to stay at the cutting edge of their sector in order to remain competitive. Supportive of this transition to a higher technology level are recent studies which find that firms which increase production with high technological content are more likely to accelerate R&D investment in the future. In this sense, ‘success engenders success’ in the production process, which in turn is associated with increasing returns to scale in the industry. In particular, Bernstein’s (1988) study of the U.S. finds that industries where the spillover of ideas is greater tend to invest more in R&D, including in basic research. Griliches (1986) study of the U.S. also finds evidence that the R&D financed directly by the firms tends to be more productive than R&D financed by the state. In this sense, tax incentives are a useful instrument to move countries away from a dependence on government financing and production of R&D, and towards greater participation and control of the private sector. In developing countries, this could come from a combination of adopting technology from developed countries and developing firm-specific knowledge.

Figure 2. R&D Investment by Source of Financing



Source: Hansen, and others., World Bank

Fiscal incentives are likely to be most helpful when designed to promote knowledge specific to the firm. It is important here to differentiate between general knowledge and specific knowledge. The first is non-exclusive, and has to do with the development of ideas and basic research. Such research is rarely profitable but has great externalities through enormous spillover effects, so there is a legitimate role for the state to take on its financing. Specific knowledge, on the other hand, benefits the firm directly. A well-functioning patent system would allow the firm to appropriate the benefits, but when such a patent system does not exist (or the risk of copying is great, as is more common in developing countries) R&D investment or tax incentives may be more suitable. Table 1 summarizes the existing tax incentive systems of specific countries.

Table 1. R&D Fiscal Incentives in Selected Countries

Country	Type of incentive		Description		Special treatment for small and medium-sized firms (SMEs)
	Tax credits	Description	Description	expenditure to which it applies	
Australia	No	Yes	A combination of deductions of the expenditure levels and expenditure increments. 125% over expenditure levels. Additionally, a deduction of 175% for the average of increments over the past three years.	Current expenditures and investment in machinery and equipment	18.5% deduction 35% tax credit. Refund if firm has no tax liability.
Belgium	No	Yes	13.5% of the level of R&D expenditures	Investment in machinery, equipment and buildings.	
Canada	Yes	No	20% of the level of R&D expenditures	Current expenditures, machinery and equipment	
Denmark	No	Yes	125% of the level of R&D expenditures	Current expenditures, machinery and equipment and structures	
France	Yes	Yes	40% applied to R&D increment, compared to the average R&D expenditures of the two previous years.	Current expenditures, machinery and equipment and structures	Refund
Italy	Yes	No	30% applied to R&D expenditure level	Current expenditures, machinery and equipment and structures	Only applies to SMEs
Japan					
Regular			15% of incremental expenditures, compared to R&D average expenditure of the previous 3 years.	Current expenditures and machinery and equipment	
SMEs	Yes	No	10% of R&D expenditure level	Current expenditures and machinery and equipment	
Technology-based			5% of R&D expenditure level	Machinery and equipment	
co-op R&D			6% of R&D expenditure level	Current expenditures, machinery and equipment and structures	
Korea					
SMEs	Yes	No	15% of R&D expenditure level and 50 percent of the incremental expenditure	Current expenditures	
large firms			50% of incremental R&D expenditures, compared with the average of the previous 4 years	Current expenditures	
Mexico	Yes	Yes	Tax credit for incremental R&D tax expenditures compared with the previous year. Income tax deduction for donations to funds used for R&D financing up to 1,5% of the donor's income and 1 percent if destined to special programs.	The tax credit applies to current expenditures.	
Norway	No	Yes	20 percent of R&D expenditure level	Current expenditures	
Portugal		No	20% of R&D expenditures. 50% of incremental expenditures compared with the average of the past 2 years.	Current expenditures	
Spain	Yes	No	30% of R&D expenditure levels. 40% of incremental expenditures compared to the average of the previous 2 years. Capital expenditures receive a tax credit equivalent to 10 percent of the expenditures.	Current expenditures, machinery and equipment	
U.K.	No	Yes	125% of R&D expenditure levels	Current expenditures	150%
USA	Yes	No	20% of incremental expenditures. Maximum 50% of current expenditures.	Current expenditures	
Colombia	No	Yes	125% of investments and donations to projects that qualify as being scientific and innovative in character according to Colciencias. This deduction cannot exceed 20 percent of gross income of the firm.	Current expenditures, machinery and equipment	
Brazil	Yes	Yes	Income tax deduction of R&D and industrial technological activities. Technological agro activities can be deducted up to 8 percent. Tax credit of 20 percent of R&D expenditure levels.	Current expenditures, machinery and equipment	
Argentina	Yes		Tax credit for all R&D expenditures except wages and salaries. The government determines every year a budget for tax credits, which are imputed to the payment of national taxes for an amount no greater than 50 percent of the total.	Government budget for R&D projects determined limit	

Source: OECD (2004); and author.

A. Evidence from Other Countries on the Effects of R&D Tax Incentives

As table 1 shows, most OECD countries offer relatively generous R&D incentives. Indeed, the empirical literature to date has predominantly focused on studying the effectiveness of these policies in OECD countries, specifically, by estimating the price elasticity of R&D demand. For example, Bloom et. al.(2000) find that the short run price-demand elasticity of R&D investment for OECD countries is generally less than 1 (between 0.03 and 0.05), but is considerably larger in the long-run (around three times larger). Other studies, notably Hall and Van Reenen (2000), directly estimate how much R&D investment would increase as a result of a 1 percentage point effective subsidy (tax reduction) on R&D. Table 2 summarizes the results of selected studies as surveyed by Sawyer (2005). While the point elasticity varies by country and period, it implies that the rate of cost-benefit for fiscal incentives is about 1 on average, meaning that for every dollar the government loses in taxes, the additional investment in R&D is a dollar or more. This would make the cost-benefit rate on average financially equivalent to a grant program, on average.

Table 2: Comparative Studies of the Effect of Fiscal Incentives on R&D Investment

Study	Estimated elasticity of R&D investment resulting from fiscal incentives	Period of analysis	Country
Australian Bureau of Industry Economics (1993)	-1.0	1984-94	Australia
McFetridge and Warda (1983)	-0.6	1962-82	Canada
Mansfield and Switzer (1985)	-0.04 to -0.18	1980-83	Canada
Bernstein (1986)	-0.13	1981-88	Canada
Bernstein (1998)	-0.14 (short run), -0.3 (long run)	1964-92	Canada
Berger (1983)	-1.0 to -1.5	1981-88	United States
Bailand and Lawrence (1987, 1992)	-0.75	1981-89	United States
Hall (1993)	-1.0 to -1.5	1981-91	United States
McCutchen (1993)	-0.28	1982-85	United States
Hines (1993)	-1.2 to -1.6	1984-89	United States
Nadiri and Mamuneas (1996)	-0.95 to -1.0	1956-88	United States
Blomm, Griffith and Van Reenen (1999)	-0.16 (short run), -1.1 (long run)	1979-94	G-7 and Australia

Source: Sawyer (2005)

To date, surprisingly few studies of this sort have been conducted on developing countries. Perhaps the most important efforts are contained in Shah (1995b), where specific estimates for the fiscal incentive systems in Mexico and Pakistan were derived. According to Shah, Pakistan's system is not considered effective. Mani(2004)'s estimates for Brazil find that the elasticity of the tax incentive on R&D investment in the short run is a little less than 1, but the study suggests it is likely greater in the long run. Agapitova, Holm-Nielsen and Vukmirovic (2002) and Jaramillo Pombo and Gallego (2002) discuss the fiscal incentives system in Colombia within the context of the country's science and technology promotion policies. Based on secondary surveys and international comparisons, the former authors suggest that fiscal incentives have not been effective from the point of view of increasing the

participation of the private sector in R&D expenditures, at least during the 1995-1999 period under study, when public sector participation in R&D as a share of total in Colombia was equivalent to roughly 75 percent. Unlike this study, the conclusions of Agapitova et. al. are not based on estimations.

This paper also finds that the institutions that more frequently take advantage of fiscal incentives in Colombia continue to be in the public sector, the academic sector and semi-public research centers.² To our knowledge, ours is the first study to estimate elasticities for the case of Colombia.

An important issue in this regard is the sectoral allocation of fiscal incentives, as well as the type of firm that takes advantage of fiscal incentives. In this regard, the literature from advanced countries yielded some interesting results. A survey of executives in American companies showed that the fiscal incentives did not influence their strategies with respect to innovation and technology, nevertheless, these incentives were valuable to the firm in providing additional cash flow for their planned R&D activities (OECD (2004)). According to a study by the European Commission (2002), fiscal incentives did not stimulate firms to carry out additional investments in R&D if they did not already do so in the past. In contrast, the evidence for Canada suggests that fiscal incentives have indeed created additional investments across the board for Canadian firms (see for example Bernstein (1988)). Finally, most studies have shown that the fiscal incentives are taken advantage of in a greater proportion by firms in specific sectors, such as in electronics, telecommunications and pharmaceuticals, i.e., firms whose value depends on intellectual property protection (see Shah (1995b) and OECD(2004) for a detailed survey).

How does one go about comparing the generosity of the different systems? There are four basic types of tax incentives used by most countries:

- ⇒ **tax deduction** (a percentage of taxable income/profits is subtracted from the tax liability.
- ⇒ **tax credits** (a percentage of R&D expenditures is subtracted from the tax liability due)
- ⇒ **depreciation allowance** (which gives the firm some implicit up-front financing by reducing the tax liability at the beginning, but in present value terms the actual tax break may be negligible);
- ⇒ **tax exemption**, which eliminates a specific tax liability.

² The quasi-public research centers are included in this definition. These are: Cenicafe, Cenipalma, the Colombian Institute of Petroleum and various centers from public universities, and others. The first three receive the majority of their funds from the government to operate, as they are affiliated to the Federation of Coffee Growers, the Federation of Palm Oil Growers and the national oil company Ecopetrol, respectively.

Most countries offer a combination of these incentives, and in some cases they are more generous for small and medium-sized enterprises (SMEs). Many countries (including Colombia) place limits on the total amounts of credits or tax deductions that can be taken, or otherwise limit the number of entities that can apply for incentives.³

III. THE SYSTEM OF R&D INCENTIVES IN COLOMBIA AND RESULTS FROM THE FIRMS' SURVEYS

A. Background: The System of Tax Incentives in Colombia

R&D incentives are fairly new in Colombia. During the 1995-2000 period, the fiscal incentives in Colombia operated from a small office in the National Planning Department ((Departamento Nacional de Planeación) and the number of applications/acceptances of the tax deduction were less than a third of what they were in 2001. The process was also slower. In 2000 the responsibility was transferred to Colciencias (*Colombian Institute for the Development of Science and Technology Francisco José de Caldas*, the autonomous government agency in charge of promoting science and technology), which proceeded to closely weave the incentives to its existing grant-making process.

Under Colombian Law, entities can apply to the following R&D-related incentives:

- **A tax deduction of 125 percent** on the value of a project of science and technology previously evaluated and approved by Colciencias as being innovative in character. For the case in which the financial resources for an R&D project are donated, the tax deduction confers to the donor's taxable income. This paper will focus on the economic effects of this incentive. Non-profit organizations and educational institutions such as universities are already exempt from income taxes under Colombian law, so the R&D tax deduction is not useful for them.
- Imports of certain capital goods for technology projects by non-profit organizations and educational institutions are also tax exempt. Under this modality, do not have to follow a pre-approval process.⁴
- **A 16 percent VAT exemption on imported machinery, equipment and raw materials** used by a university or research institution in a research or scientific project previously approved by Colciencias. It is managed by Colciencias as well. This incentive is fairly

³ Within the group of middle-income countries in Latin America, only Mexico, Brazil, Argentina and Colombia offer fiscal incentives.

⁴ This modality is managed by the Ministry of Industry and Commerce. Nonetheless, Law 633 of the 2000 states that any granting of exemptions, tax discounts and other fiscal incentives for the purposes of fomenting scientific and technological activities required prior approval from Colciencias.

small in scope and it is rarely used: the fiscal cost to the government is less than 3 percent the cost of the 125 percent tax deduction. Part of it has to do with its design.⁵

- **Income tax exemption for profits on software and natural medicines.** As part of the 2003 tax law, new incentives were created which allow national software developers or those with natural medicinal products using Colombian raw materials to be exempted from profit taxes for a period of 10 years following the approval of the application, if it is deemed sufficiently innovative. As of 2004, only 20 applications—and 16 approvals had been made for software, and none for the development of natural medicines.

Table 3. Fiscal Cost of the Main Tax Incentives in Colombia
(in billions of Colombian pesos unless otherwise indicated, 2005)

	Beneficiary tax base	share in total (%)	fiscal cost	share (%)
Exempt Income	4554	64.5	1502	60.3
<i>of which</i>			983	39.5
Free trade zones	14	0.2		
Páez Law	396	5.6		
Quimbaya Law	11	0.2		
Reforestation	3	0.0		
Large public taxpayers	694	9.8		
temporary 30% Mach. & equip. deduction	2336	33.1	860	34.6
Tax reductions 1/	84	1.2	84	3.4
Total tax benefits	6974	98.8	2447	98.3
Income tax deductions for R&D investments and donations (2004)	88	1.2	42	1.7
Total including R&D deductions	7062	100.0	2489	100.0
Memo item: total as a percent of GDP	2.53		0.9	

1/ Includes sales tax reductions for the heavy machinery imports used in basic industry

Source: DIAN (Colombian revenue authority) and author

The merits of the R&D tax deductions have to be measured relatively, within the context of the rest of the tax system.

- **There are various other tax incentives in the Colombia which are generally much more generous** (thus more expensive for the government), and easier to acquire than the R&D tax incentives. Table 3 shows the fiscal costs of the main tax benefits conferred under the 2005 Colombian system (see discussion in section IV.C below).

⁵ First, it is even less well-known that the tax deductions, and applies only to imports. Second, machines and instruments purchased under this modality have to be specified ahead of time, when the project for which they will be used is submitted for the consideration of Colciencias, and in many cases the need of materials and instruments is only identified in the course of the research work. This also means that the administrative cost for the applicant of a small instruments (say, a microscope) often exceeds the 16 percent tax exemption benefit. Third, the materials or instruments cannot be used for other purposes, such as for example, to equip a lab at a university. They can only be used on the pre-approved research project.

- An additional quirk in the Colombian R&D tax incentive system is that **income tax-exempt institutions frequently apply for the 125 percent income tax deduction** despite it conferring no additional financial benefit. They do this to obtain a “seal of approval” of sorts, confirming the high scientific quality of the proposed projects.
- **Moreover, amounts budgeted for the remuneration of researchers is not eligible for this tax deduction.** In many cases it constitutes the bulk of the cost.
- Nonetheless, with an income tax rate for firms of between 35 percent and 38.5 percent, **the fiscal incentive can end up being relatively generous.**
- **Unlike most other exemptions and other countries, the application process for the 125 percent tax deduction is relatively rigorous.** A firm wishing to obtain an R&D tax deduction on a specific project must submit a detailed project proposal, which must be accompanied by a budget and other pertinent financial information. This deduction is not automatically granted ex-post if the firm meets certain conditions. The process is rigorous and dependant on outside experts who evaluate the ‘innovative’ character of the project on a referee basis (without knowledge of the identity of the applicant). The final decision and resolution is made by a committee which meets about 4 times a year, the so-called *National Council of Science and Technology (CONCYT)*.⁶

Other Concerns of the Present System: a Legacy of the Past

Interviews with applicants and Colciencias staff conducted by the author and past studies suggest that the application process in Colombia, while transparent, efficient, unbiased⁷ and fraud-proof still has some way to go before it can engender a critical mass of industry-specific research financed by the private sector in Colombia. The main reasons are the following:

Public sector dominance: It is important to note that about 47 percent of the approved applications are granted to public enterprises, and 8 percent to entities affiliated with universities. In public finance terms, this essentially constitutes a transfer of funds from one public sector agency to the other, thus further reducing the net fiscal impact of the program. The largest benefactor of the tax deduction is the research arm of Ecopetrol, the state oil company. On the downside, it reduces the net total additional incentive to the private sector. This relates to a point made by Nolan and Pack(2003), in which the low relative share of

⁶ The Council consists of the relevant Ministers (Education and Agriculture, for example), Presidents of both public and private universities, as well as other prestigious leaders of the scientific community.

⁷ We tested whether the qualification process carried out by Colciencias yielded biases for or against a certain type of project. We ran a Probit regression where the dependant variable was 1 if the project was approved (0 otherwise) and the independent variables consisted of variables indicating the type of project (for example whether the project was from a public or private institution), and the size of the applying institution (in assets). None of these variables were statistically significant, suggesting that a firm’s project is neither more nor less likely to be accepted because it has one of these characteristics. Therefore, the process was deemed unbiased.

R&D expenditures that come from the private sector in Latin American countries harks back to the era of import substitution and protectionism, where the objective was to promote the national industry. This is evident in the distribution of firms in Figure 3.

Table 4. Applications and Acceptances of R&D Incentives by Year and Type of Tax Incentive
(in numbers)

	2001	2002	2003	2004	Total	Share (%)
1. Number of applications						
Type of incentive						
Software	0	0	0	26	26	3
Donation	1	7	8	9	25	3
Investment tax deduction	61	129	95	109	394	46
VAT exemptions	101	108	115	91	415	48
Total	163	244	218	235	860	100
Share (percent)	19	28	25	27	100	
2. Number of Accepted Applications						
Type of incentive						
Software	0	0	0	15	15	2
Donation	1	6	5	8	20	3
Investment tax deduction	38	115	82	93	328	45
VAT exemptions	75	96	101	87	359	50
Total	114	217	188	203	722	100
Share (percent)	16	30	26	28	100	

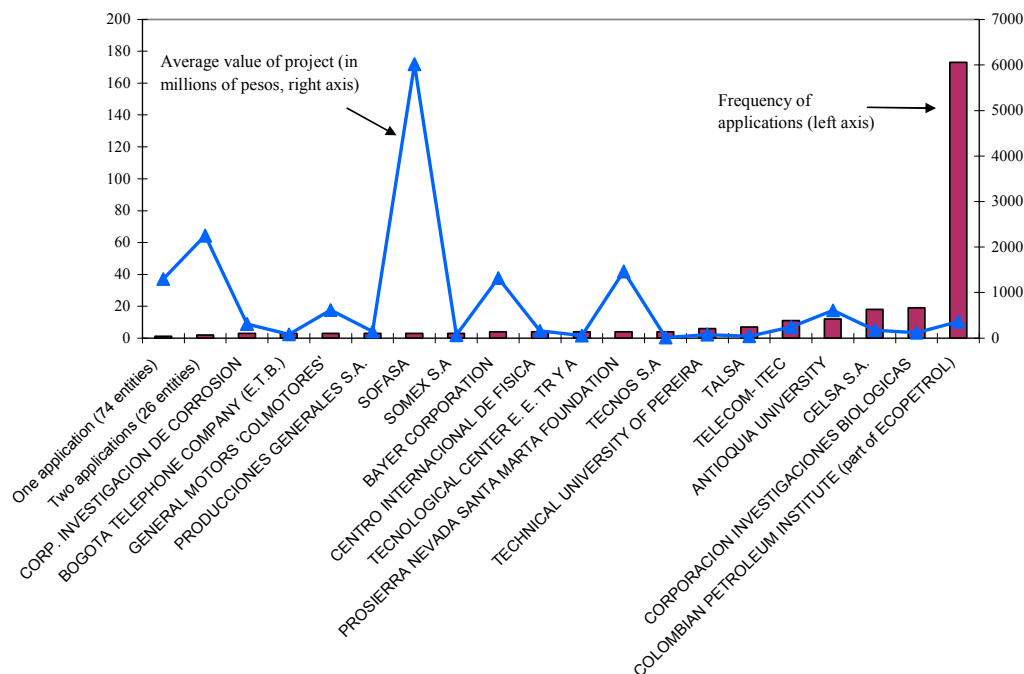
Source: Colciencias

The grant program is seldom used: As mentioned earlier, an 125 percent tax deduction is available to private individuals or entities that are willing to finance research projects executed by university or research institutions (rather than granting the deduction to the researcher directly). The benefits to the grantor can be substantial, given the income tax rate in Colombia of 38.5 percent in 2005. Nonetheless, this option is highly underutilized. It comprises about 6 percent of applications for the tax deduction (Table 4). It is unfortunate, because this is exactly the type of projects that lead to the badly needed links between researchers and private businesses that are the core of privately-financed R&D research in advanced countries. Based on interviews with academics, Fedesarrollo (2005) notes the lack of connections that exist between the academic-research sector and the enterprise sector in Colombia, and the lack of information researchers have on the needs of firms. At the same time, most of the firms in Colombia do not have the financial ability to permanently contract researchers. This point is also evident in the Fedesarrollo survey (to be discussed below), which showed that only 6.4 percent of the innovation activities performed by firms over the last three years were the result of processes developed or created within universities or research centers.

Minimal information dissemination of the existence of fiscal incentives: According to a 1995 surveys of firm regarding their knowledge of the fiscal incentives, (*Encuesta de Desarrollo Tecnológico (EDT)*, Departamento Nacional de Planeación, described in Durán et.al. (1997)), only 15 percent of firms knew about the existence of fiscal incentives. The 2005 Fedesarrollo survey (which contained firms more likely to engage in R&D) showed that

43 percent of the firms were aware of special programs offered by Colciencias, but only 13 percent of them had actually applied for tax incentives. In the EDT survey, by far the most frequently-cited reason as to why these incentives were not used were the lack of awareness about their existence. This has likely improved since 1996 with the launching of project ‘government online’ (*gobierno en linea*), where all public information is available online. Moreover, knowledge of the tax incentives was limited to just a few sectors.

Figure 3: Frequency of Applications for the 125 Percent R&D Investment Deduction and Average Value of Approved Projects in Colombia, 2001-04

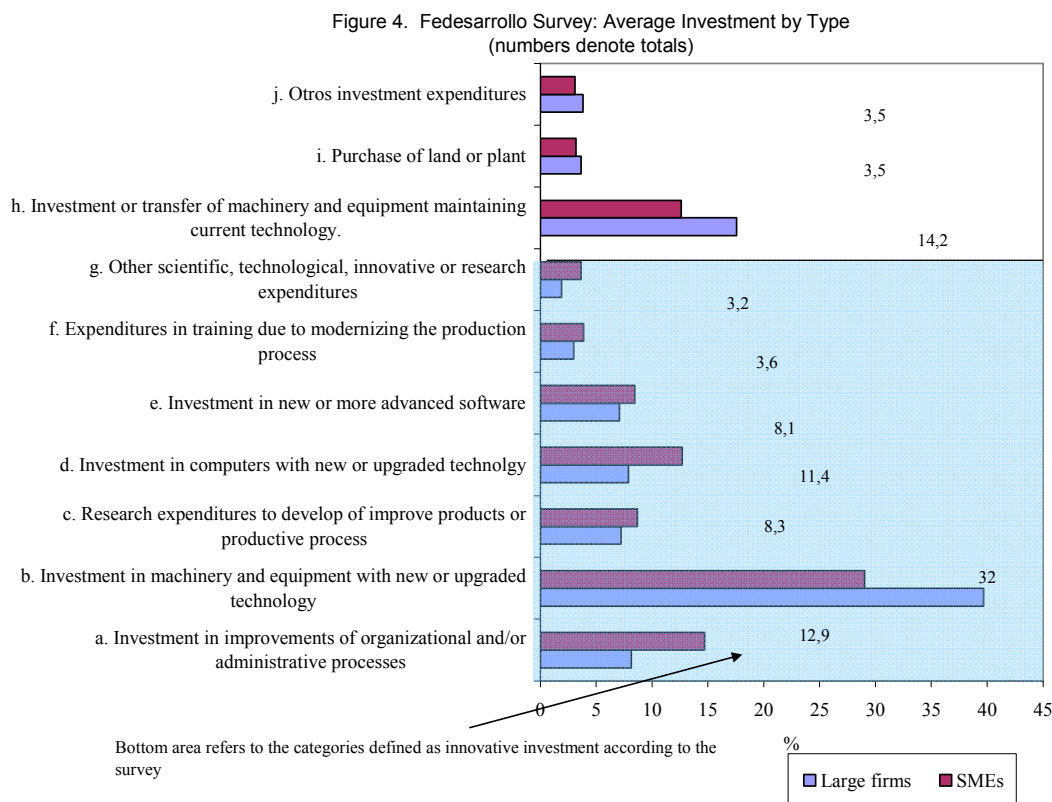


B. A Survey of Firms' R&D Activities and Perceptions

In March 2005 a special survey was conducted of 261 firms in the manufacturing sector as part of Fedesarrollo's monthly enterprise survey. The results reflect the priorities and reasoning behind technology and innovation decisions of Colombian firms. The conclusions that are borne out from the responses turned out to be quite consistent with the results of the econometric analysis.

As part of the design of the survey, a somewhat broader definition of innovation was adopted compared to the manufacturing R&D survey. For example, if a firm engaged in a machinery upgrade which increased the efficiency of the process to a significant degree, or altered the production process, it was classified as R&D investment for the purposes of the Fedesarrollo survey. Note that this was markedly broader than the definition of Colciencias or the Survey of Manufacturing (used in the econometrics), which explains why on average firms in the fedesarrollo survey appears to be more technologically advanced than in the

other data sets. The definitions of R&D investment in the survey were classified into seven types (labels a to g in the lower, shaded quadrant of Figure 4).



The results for the sample are shown numerically. The blue and crimson bars represent the disaggregation by large and small firms, respectively. The main results were:⁸

- While only 32 percent of total investment constituted innovation, on average, larger firms tend to invest a greater share in new technology relative to small and medium-sized firms (40 percent for large firms versus 29 for the rest).
- Larger firms tend to be much more satisfied with the current level of R&D investment compared to the rest (over 50 percent of firms are large). Small and medium-sized firms were much more likely to report that they were not investing as much in innovative activities as they wanted to. Further questioning revealed that the need to seek outside credit was an issue: more than a quarter reported that the biggest obstacle to increasing investment in innovative technology was related to financial constraints.
- When asked what were the greatest obstacles to R&D investment, larger firms were more likely to point to the macroeconomic environment, whereas smaller firms cited internal

⁸ See Fedesarrollo (2005) for a detailed analysis of the survey.

factors specific to their firm. For example, many large firms pointed to demand uncertainty, political instability or exchange rate movements. Small firms were more likely to cite the lack of an appropriately skilled workforce, as well as the possibility that the secret would be ‘stolen’ by competitors.

- According to some of the questions, most of the achievements in innovation was the result of efforts within the firm. Only 6 percent of firms surveyed noted that they had cooperated with research institutions of technical development centers. This was true for both small and large firms.
- The survey also tried to gauge whether the mechanisms used to deliver the incentive were adequate. It asked firms which would be their preferred form of delivery of a \$1-worth of R&D incentives: through a direct subsidy, a tax credit, technical assistance, training of skilled workers, a tax deduction or a VAT rebate. Large firms preferred its delivery via the tax system, particularly through an income tax deduction, whereas the rest were split relatively equally between a VAT exemption, an income tax deduction or a tax credit/direct subsidy.⁹

Do Firms Understand the Importance of Science, Technology and Innovation?

One of the most interesting aspects that was brought out clearly in the survey is that Colombian firms do understand the importance of science and technology in the development of their firm. The majority of firms responded that research, technology and innovation had a highly positive effect on their firm, namely, by making the firm more competitive. Moreover, more than 80 percent of firms across all types felt that the topic of science, technology and innovation was highly relevant to the firm’s development. 56 percent of firms noted that research was important to the firm because of its direct and positive effect on profitability and competitiveness. Also, consistent with earlier surveys and interviews (as discussed above), most firms were aware of the existence of Colciencias, but less than 20 percent knew that they offered fiscal incentives.

Given that most Colombian companies understand the importance of R&D for their development, the scant use of fiscal incentives suggests that it may have to do in large part to the lack of information dissemination on the subject. The only information on the tax incentives appears somewhat hidden within Colciencias’ web page. More importantly, The Directorate of Taxes and National Customs of Colombia (DIAN), the main tax authority, does

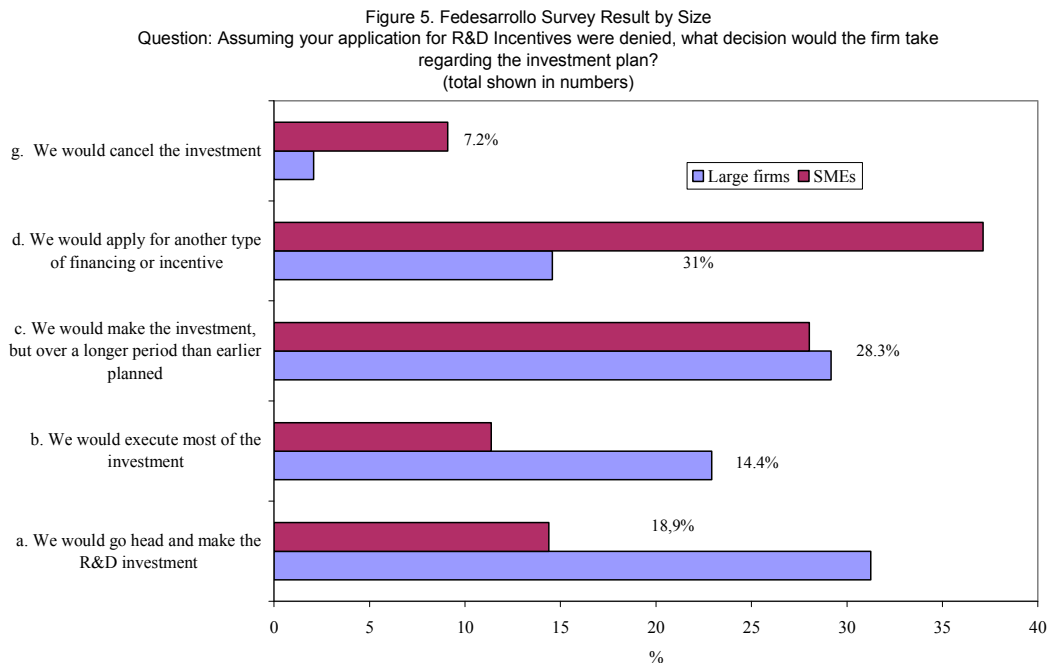
⁹ This question likely also reflected the incentives in the context of the broader Colombian tax system: the VAT is borne by all firms, whereas other taxes tend to have a greater incidence on the profitability of large firms. Note that the ‘other’ firms in the sample are on average much larger than the average size of a Colombian firm. Of course, small ‘mom and pop’-type operations, which may be exempt from income tax, are not included in the sample survey.

not offer any information on these incentives in its web pages or its customer service centers. Indeed, some DIAN officials were unaware of their existence. Instead, the information lays harbored for easy access to academic or research institutions which typically apply for grants, not tax incentives.

Firm's Size and Financial Constraints

The survey results were spliced in different ways and by different criteria, but the results did not differ significantly if grouped according to criteria other than size and financial constraint. This is consistent with findings by other studies of a high correlation between size and degree of financial constraints: large firms were less likely to be financially constrained.

The survey results clearly shows that larger firms and less financially-constrained firms do not need the tax incentives as much as other firms.¹⁰ When asked what they would have done had their application for tax incentives been denied, 83 percent of large firms said they would go ahead and make the investment anyway (some with a delay). In contrast, only 25 percent of SMEs said they would make the full investment without incentives; they were more likely to search for additional options (see Figure 5). Not surprisingly, financially-constrained firms were less likely to carry out the investment project *expost* had their application to Colciencias been denied.



Characteristics of Applicant Firms that Received Fiscal Incentives versus Those that did Not.

The survey results were disaggregated according to whether the firm had received incentives from Colciencias or not. Table 5 shows that firms that received tax incentives tend to be larger and more outwardly oriented towards the export market. As to their responses in the survey, there were significant differences only in four areas:

Table 5: Characteristics of the Firms Surveyed in the Fedesarrollo Survey of Manufacturing and R&D 2005
(in percent unless otherwise indicated)

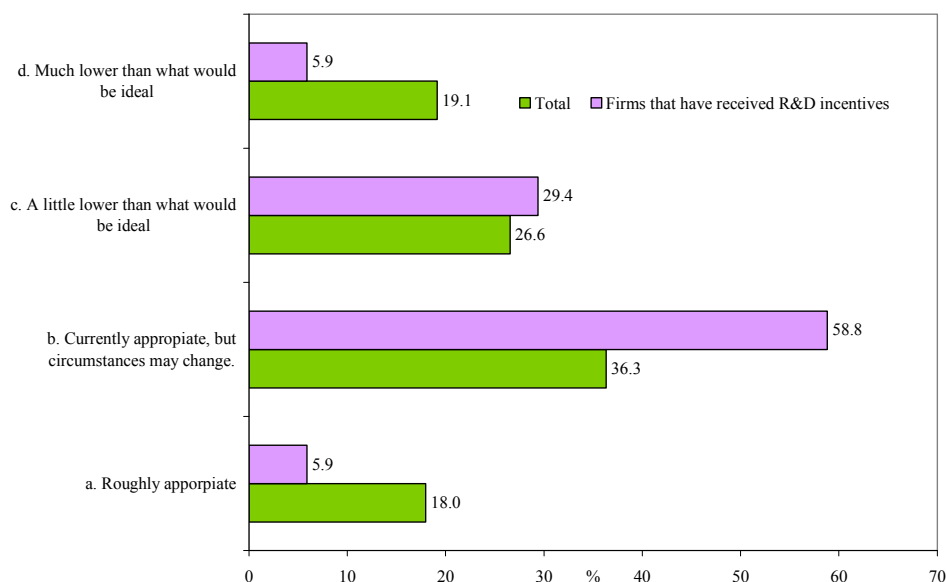
	Average for sample which had project approved by Colciencias	Average values for total sample
Assets (millions US\$) 1/	69.0	22.6
Share of large firms (assets greater than 20 billion pesos in 2005)	65	28
Average value of project approved for R&D deduction (millions US\$)	0.8	...
Share of firms which export	82	61
Share of exports over sales	28	15

Source: Fedesarrollo survey and *Superintendencia de Sociedades*

1/ Using an exchange rate of 2,000 Col. Pesos/US\$

- A greater percentage of firms that received the R&D incentives stated that the level of technology investment expenditures by the firm were adequate (Figure 6).

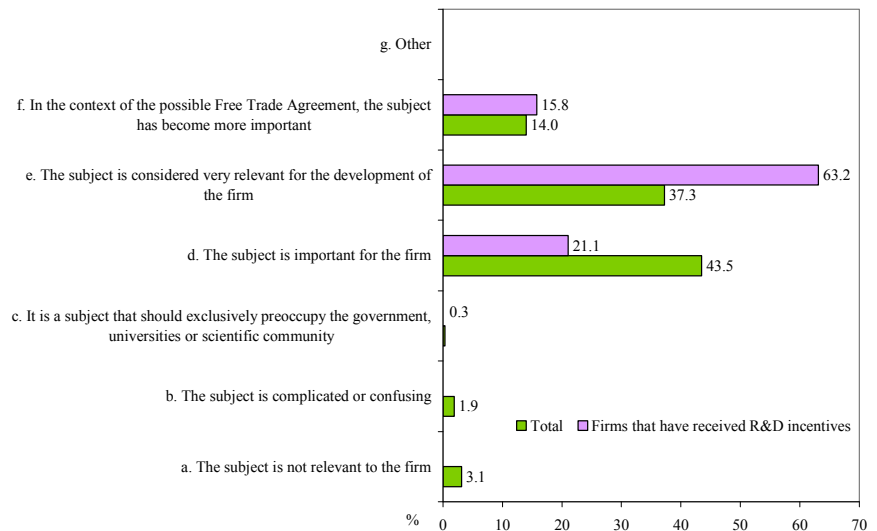
Figure 6. Question 3, Fedesarrollo Survey: The level of R&D Investment Currently done by Your Firm Is:



¹⁰ 17 percent of the firms in the Fedesarrollo survey had applied for fiscal incentives, and this was relatively evenly distributed between large and small firms.

- A larger percentage of firms that received R&D incentives stated that the most important role science and technology played in the firm was that it increased profitability (Figure 7).

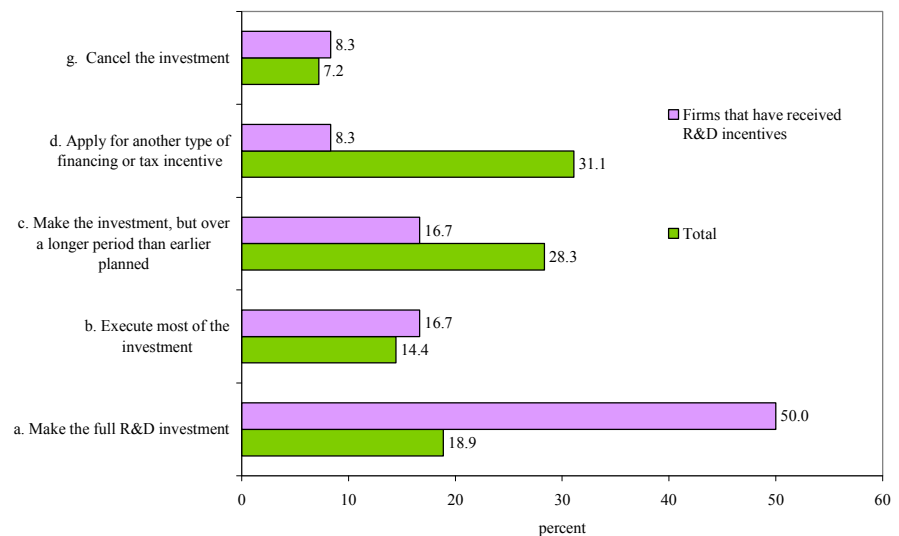
Figure 7. Question 10 Fedesarrollo Survey: What is your firm's perception about the subject of science and technology?



- Not surprisingly, a larger proportion of the R&D incentives users considered that science and technology was a very relevant aspect for the development of the firm.

- Finally, when firms were asked what they would have done had their application for R&D incentives been rejected, 84 percent of firms that received them reported that they would still have made the investment even if they had not received them (Figure 8). This compares to 63 percent for the sample as a whole. Moreover, 50 percent of the firms that actually received R&D incentives responded that they would have carried out the full investment project without delay, with or without the incentive. This result was the most telling of the survey, because it suggests that the *firms actually receiving the fiscal incentives are those that need them the least*. They also mirror some of the results of similar surveys in the United States, surveyed in Shah (1995))

Figure 8. Question 13 Fedesarrollo Survey: Assuming your application for R&D Incentives was denied, what decision would the firm take regarding the investment plan?



Characteristics of firms that apply for R&D incentives.

To rule out the possibility that these results may be affected by some type of bias in the application process, a Probit analysis was also conducted to check whether the firms that tend to apply to Colciencias have certain characteristics that are different from those that do not. This would be an important policy question if the government wants to consider changing the existing policy. The method and results are shown in Annex 1, where the sample includes a broader set of firms than those used in the Fedesarrollo survey. The dependant variable is a dichotomous variable equal to 1 if the firm applied for tax incentives and 0 otherwise. The equation tries to infer: (i) whether firms that apply tend to have more financial constraints; (ii) whether they tend to invest more in R&D; (iii) whether they are larger (measured by assets); (iv) whether they are recurring applicants, more likely to have applied for Colciencias R&D incentives in the past; and (v) whether the firm had benefited in the past from research, as proxied by the share of ‘intellectual assets’ (such as patents, registered marks, etc) in total assets.

The results show that larger firms and recurring applicants are more likely to apply for the fiscal incentives. This, to some extent, is consistent with the survey results shown in Table 5. Moreover, firms that have applied before are more likely to apply again. A possible explanation for this may be that any initial apprehension encountered in the process was likely gradually overcome, making it more likely that a firm would continue applying, which bodes favorably of the system. Other characteristics did not seem to significantly affect the chances that the firm would be more or less inclined to apply.

IV. ECONOMETRIC RESULTS: R&D INVESTMENT INCENTIVES TO PRODUCTION IN THE COLOMBIAN MANUFACTURING SECTOR

This section uses econometric estimates to infer the behavior of R&D investment by manufacturing firms in Colombia between 2000 and 2002. We first describe the data, then assess the econometric results for the full sample, and well as by size and degree of innovation. We also look at the fiscal implications of the current program.

A. Characteristics of the Data

The analysis uses data from the *Annual Survey of Manufacturers* of DANE (National Administrative Department of Statistics) disaggregated by establishment,¹¹ which contains more than 19,000 observations (establishment-year). This dataset has been used in many other prominent studies of Colombia. What is new here is that this study was the first to have access to a special module of the survey, called the ‘Technological Innovation’ module.

¹¹ The establishment is the definition of a production unit. For example, a company with 4 plants probably has 4 establishments.

This module has detailed establishment-level data on R&D expenditures as well as the number of technical workers engaged in R&D and innovation activities, but was only available for the 2000- 2002 period. Note that the definition of R&D expenditure in this survey is much narrower than for the Fedesarrollo survey, and more consistent with international definitions of R&D activities. After discarding questionable data, the sample used had 5,274 observations.¹²

There are only minor differences in the production characteristics of the firms that applied to Colciencias relative to those that did not (Table 6). The firms that applied for R&D tax incentives are slightly more innovative (spending 1.8 percent of expenditures on R&D investment, versus 1.5 percent for the total sample), but in either case, these expenditure shares are very small. Moreover, compared to the total sample of firms, those that applied to Colciencias have half as many workers engaged in technological activities as a share of total workers (15 versus 8, respectively). Still, no major difference in the average capital intensity of either type of firm is observed. It is noteworthy that more than 50 percent of the investment firms' costs seems to go to raw materials.

Table 6. Characteristics of Manufacturing Establishments in the DANE Science and Technology Sample
(average values, 2000-2002)

	Full sample	Applicants to Colciencias
<i>(in millions of current pesos unless otherwise stated)</i>		
Total technological innovation	6,058,118	7,618,491
of which:		
purchases of R&D machinery equipment and new technologies	5,657,972	7,380,688
Sales	395,000,000	414,000,000
(in millions of current US dollars)	174,162	182,540
<i>(number)</i>		
Total number of employees (labor administrative, directive, technical)	2,992	406
of which		
technical	220	53
personnel engaged in R&D	15	7
(as a share of total employees, percent)	0.52	1.71
<i>(in percent)</i>		
Expenditures as a share of sales		
R&D expenditures	1.5	1.8
Raw materials	45.8	51.7
Fixed factors (land, equipment)	4.7	3.0
As a share of total R&D expenditure		
R&D machinery and equipment and new information technologies	93	97
Expenditures in technologies developed internally by the establishment	1	1
Share of capital equipment expenditure in the costs on all inputs	5.4	3.4
Number of establishments	508	17

Source: Annual Manufacturing Survey, Science and Technology Module, DANE

¹² Only 17 firms had applied for R&D tax incentives from Colciencias. This should not bias the results in any way, as the main objective of this section is to measure the effect of R&D investment of a 1 percent reduction of the price of R&D (whether due to a fiscal incentive or simply a reduction in the price).

Among the reported R&D expenditures, the largest share is spent on so-called quasi-fixed factors such as ‘R&D machinery and equipment’ and ‘new information technologies’.¹³

This suggests that innovation is incorporated in the machines, thus reflects adaptation of outside technologies to the processes of the firms in question.¹⁴ Only 1 percent of the total R&D expenditures represent the so-called ‘technologies developed by the establishment’.

In terms of size, large manufacturing establishments are somewhat more innovative than smaller ones. Table 7 shows that large companies spend 1.8 percent of their sales on R&D expenditures (compared to 1 percent for medium-sized companies and 0.7 percent for small companies). In addition, the proportion of people occupied in R&D activities relative to the total is greater the larger the size of the company. Moreover, the large firms tend to be more capital intensive: the share of fixed capital costs in total production costs is 6 percent, double compared with the proportion for small companies. Finally, the fixed assets constitute a greater proportion of the sales for the large companies (66 percent) compared with medium (55 percent) and the small ones (38 percent).

B. Model Set-up and Estimation of the Production Coefficients

The main analysis consists of estimating a system of simultaneous equations of costs and factor demands which together describes the production structure of each establishment.

The methodology and data are described in detail in Annex 2. The purpose is to calculate own-price elasticities as well as cross-price elasticities in order to answer the following questions:

- How much more do Colombian firms invest for every percentage point fall in the cost of R&D investment?
- What are the effects on R&D investment if the prices of other factors of production change?
- What is the elasticity of substitution, in other words, what is the percent change of R&D investment for every 1 percentage point increase in the demand for other factors? This is also important when designing tax incentives because if it is found that incentives to invest in machinery and equipment raise the demand for R&D, this could be considered an indirect R&D incentive. Conversely, an increase in the use of R&D may decrease demand for other factors.
- Whether the firm’s productivity increases significantly as a result of greater R&D investment (the output elasticity of R&D). As other studies have shown, this elasticity tends to be considerably greater in the long-run than in the short-run, but we are not able

¹³ Box 1 describes the six sub-types of R&D expenditure defined in the module.

¹⁴ An issue in all these studies is the difficulty of classifying expenditures into those that may lead to activities that create new knowledge, and those who adapt new technology for the firm (see discussion below). Here the definition includes any type of machinery that could increase the technological base of the firm in question.

to calculate the long-run elasticity. With so few years of data and given that the program is relatively new, it is not possible to get a reliable long-term estimate. According to theory and evidence in other countries, the learning-by-doing process of adopting new technology should allow the investment to become more productive over time.

- Whether the additional investment in science and technology by firms is greater than the fiscal cost of the incentives.

Table 7: Characteristics of Manufacturing Establishments According to Size 1/
average values, 2000-2002 2/

	Total	Small	medium-sized	large
<i>(in millions of current pesos)</i>				
Total technological innovation	6,058,118	660,506	2,475,823	15,900,000
of which:				
purchases of R&D machinery equipment and new technologies	5,657,972	595,621	2,243,944	14,890,306
Sales	395,000,000	101,000,000	244,000,000	885,000,000
Total expenditures on productive factors	231,461,240	64,375,659	147,077,275	509,922,645
Electricity consumed	59,300,000	8,501,127	27,200,000	151,000,000
<i>(number)</i>				
Total number of employees (labor administrative, directive, technical)	2,992	1,389	2,342	5,481
of which				
technical	220	78	155	449
personnel engaged in R&D	15	4	11	32
<i>(as a share of total employees)</i>	0.52	0.31	0.48	0.59
<i>(in percent)</i>				
Expenditures as a share of sales				
R&D expenditures	1.5	0.7	1.0	1.8
Raw materials	45.8	51.6	48.0	44.6
Fixed factors	4.7	2.9	3.7	5.2
labor costs (wages, salaries, benefits, etc)	8.1	9.3	8.7	7.8
As a share of total R&D expenditure				
R&D machinery and equipment and new information technologies	93	90	91	94
Expenditures in technologies developed internally by the establishment	0.9	1.4	1.6	0.8
Stock of fixed production factors (thousands of current pesos)	237,942,344	38,178,651	124,027,207	584,266,251
<i>(as a percent of sales)</i>	60	38	51	66
Share of capital equipment expenditure in the costs on all inputs	5	3	4	6
Number of establishments	508	177	172	159

Source: Annual Manufacturing Survey, DANE

1/ the classification by size is done according to the gross nominal output of the establishments

Variables and Model Construction

We follow Shah's (1995) methodology, which invokes Sheppard's Lemma to convert equations that describe the production technology into a system of costs and factor demands.

We define five factors of production, two of which are quasi-fixed inputs (in that they generate a ‘service’ every period): physical capital, such as machinery and equipment, office equipment, vehicles, and structures (denoted ***kme***); and capital expenditures in R&D and innovative processes¹⁵ (denoted ***krd***). The other three factors are variable factors: intermediate consumption (made up of raw materials and consumption of electricity, ***ci***), and labor (made up of other occupied personnel, including technicians, administrative and directive personnel, denoted ***l***). Administrative labor is included in the analysis because their work presumably can enhance the company’s efficiency (through marketing, training and strategy functions, etc), despite not being involved directly in the production process. Finally, the fifth factor of production consists of other costs, such as administrative expenses, incidental expenses, land acquisitions, etc. (denoted ***oc***). This last factor can be considered as a combination of fixed and variable factors.

Box 1. Description of Factor Demand Variables

- ***Kme***: physical capital, consisting of machinery and equipment, office equipment, transport equipment, buildings, structures and other nonresidential construction;
- ***Krd***: R&D capital, made up of 6 sub-factors: (i) machinery and equipment used in modernization; (ii) lab equipment and other specialty items used innovative activities; (iii) new information and communications technologies; (iv) training and technical assistance for skilled workers; (v) quality control, securing and certification expenditures; and (vi) new technologies developed by the establishment proper.
- ***Ci***: Intermediate consumption made up of the consumption of raw materials and the purchase of electrical energy.
- ***L***: total employed labor
- ***Oc***: other costs, corresponding to operational and non-operational acquisitions of land such as rentals, administration, advertising and marketing, and all others.

Each one of these factors has a price. In the case of quasi-fixed factors, the price is constructed to reflect the effective price of the ‘service’ the machine generates in a particular period, i.e., the user cost of capital. Therefore, the acquisition price of a capital good is defined as:

$$p_i = q_i * (r + \delta_i) * (1 - u) \quad \text{if } i = \text{quasi fixed factor}$$

where:

i = type of capital (land, buildings and structures, constructions in progress, transport equipment, machinery and other office equipment). If the machinery and equipment are used for R&D or as part of a new technology, they are considered part of R&D capital (***krd***) otherwise they are part of machinery and equipment. (***kme***).

¹⁵ Which could include fixed capital (specialized equipment) or human capital involved in R&D.

q_i = relative purchase price of a unit of the quasi-fixed factor i

p_i = effective price of the quasi-fixed factor i .

r = discount rate (10 percent per annum, assumed equal for all i).

δ = annual depreciation rate (declining balance), which differs for each factor. Standard values from well-known international studies are used.

u = income/profit tax rate. During the analyzed period (2000-2002), the profit tax rate in the manufacturing sector was 35 percent in Colombia.

All the factors of production in the analysis are made up of several sub-factors (except for labor, where the effective price is the average wage rate per worker of the firm). Therefore, to calculate the price of the factor i , which we assume is made up of h sub-factors, a weighted sum of the sub-factors is constructed. For each sub-factor h the total cost of factor i is:

$$p_i = \sum_h w_h p_h$$

where: w_h it is the participation of the cost of sub-factor h in the cost of the factor i , and p_h is the effective price of the sub-factor h . For example, the intermediate costs factor is made up of electricity consumption and raw materials. Therefore, w_h of raw materials is equal to the share of raw materials costs in total costs of energy and raw materials of the firm. The construction of the other factors is described in detail in annex 2.

For firms that receive the R&D tax deduction of 125 percent, the effective price of the R&D factor must be lower relative to other firms. If a given fixed sub-factor h receives the tax deduction, the effective price of that sub-factor is:

$$p_h = (1-s_n) q_h (r+\delta_h) (1-u) + s_n (q_h (r+\delta_h) (1-u (1+z)))$$

where:

s_n is the share in total R&D expenditures of firm n which qualifies for R&D tax deductions; and

z = additional depreciation deduction, equal to 25 percent for the case of Colombia¹⁶. For firms that did not apply for the fiscal incentive or had their application denied, s_n is equal to zero.

¹⁶ If the cost of fixed factors which qualify for accelerated depreciation can be written off immediately, the deduction of 125 percent permitted by Colciencias' fiscal incentive implies that the only additional effective incentive is the difference, 25 percent.

q_h = unit factor price. The other variables are defined as above.

If one of the variable factors i is used in R&D, its effective price is defined as:

$$p_i = (1-s_n)*p_h + s_n p_h * (1-u_z)$$

which states that the effective price for a variable factor approved for the tax incentive by Colciencias is 25 percent lower, multiplied by the income tax rate u , paid by the firm. If this refers to an expense that can already be deducted from income according to the tax code, the additional benefit would only be 25 percent, also multiplied by the income tax rate, u .

Table 8 shows the descriptive statistics of the price and share variables for the full sample. S_i denotes the share of factor i 's expenditure in total costs, and Q_r denotes real output, proxied by production in constant pesos. The table shows that the shares of intermediate consumption and other expenditures dominate, constituting 43 and 39 percent of total costs, respectively.

Table 8. Simple Statistics of the Main Price and Share Variables
5274 observations

Variable	Average	Standard deviation
Prices, p_i		
P_{kme}	0.211	0.069
P_{krd}	0.406	0.439
P_l	1	0.767
P_{ci}	1.24	0.069
P_{oc}	1.245	0.085
P_Q	1.21	0.096
Shares of expenditures in total costs, S_i		
S_{kme}	0.021	0.049
S_{krd}	0.023	0.037
S_l	0.203	0.122
S_{ci}	0.433	0.187
S_{oc}	0.319	0.152
Average production (millions of 2000 Colombian pesos)		
Q_r	20,800,000.00	88,300,000.00

For the estimation, we postulate a translog production function $C(Q, P; t)$, which can thus be represented as follows:

$$\begin{aligned}
C = & \alpha_0 + \alpha_Q \ln Q + \frac{1}{2} \gamma_{QQ} \ln Q^2 \\
& + \sum_{i=1}^5 \alpha_i \ln P_i + \frac{1}{2} \sum_{i=1}^5 \sum_{j=1}^5 \gamma_{ij} \ln P_i \ln P_j \\
& + \sum_{i=1}^5 \gamma_{QP_i} \ln Q \ln P_i \\
& + \phi_t t + \frac{1}{2} \phi_{tt} t^2 \\
& + \sum_{i=1}^5 \phi_{tP_i} t \ln P_i + \phi_{tQ} t \ln Q + \varepsilon
\end{aligned} \tag{1}$$

where C = total costs = $\sum_{i=1}^5 P_i X_i$ and

P_i = price of input i , where $i = kme, krd, ci, l, oc$

X_i = quantity demanded of input i

Q = the value of production

t = technical change, proxied by a time trend

The translog cost function is a second-order logarithmic Taylor series expansion of a twice differentiable analytic cost function around unity. Cost-minimizing derived-demand equations for the various inputs are obtained from the cost equation by logarithmically differentiating this function with respect to input prices and applying Sheppard's lemma, that is, $\frac{\partial C}{\partial P_i} = X_i$. The derived-demand equations obtained from the process can be written as:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{P_i X_i}{C} = S_i = \alpha_i + \sum_{j=1}^5 \gamma_{ij} \ln P_j + \gamma_{QP_i} \ln Q + \phi_{it} t \quad \text{for } i=1..5 \quad (2)$$

where S_i is the share of the i th input in total cost. A 5-equation simultaneous equation system is estimated (composed of the cost function and any four of the five share equations (2)) using the method of Seemingly Unrelated Regressions, developed by Zellner.¹⁷ The results are presented in tables 9-13. Annex 2 describes the data and estimation in more detail.

Regression Results

Table 9 presents the results for the full sample, which are generally robust and have a good fit. The estimated coefficients on the right hand side have a fairly simple interpretation. For example, γ_{ij} refers to the effect of an increase in price i on factor j , all else being equal. The R^2 of the cost equation, at over 95 percent, shows a good fit, and all of the coefficients are statistically significant at the 95 percent level, with the exception of the cross-coefficient between machinery, equipment and structures prices; and the prices of other costs crossed with the time trend variable. The trend and trend squared variables also turn out to be statistically insignificant.

The simple price coefficients (α_i) can be interpreted as the change in total costs for every change in the price of factor i . Generally these coefficients are positive, unless an increase in the price of a factor leads to a sufficiently large reduction in the demand of other factors so as to actually *lower* total costs. Naturally, the sum of the α 's should be 1. In our results, they are all positive except for intermediate consumption.

¹⁷ See Kmenta (1971)

Table 9: Results of the Regression of System of Factor-costs Equations
 Estimated Parameter Values
 Method: Panel SUR, 2000-2002

	parameter	Asymptotic t-statistic
Output coefficients		
α_Q	0.451	11.15 **
γ_{QQ}	0.031	12.08 **
Simple coefficient of the 5 factor prices		
α_{kme}	0.027	3.02 **
α_{krd}	0.046	6.49 **
α_{ci}	-0.396	-11.77 **
α_l	0.754	38.89 **
α_{oc}	0.569	19.21 **
Cross-coefficients of factor prices , where $\gamma_{ij} = \gamma_{ji}$		
$\gamma_{kme,kme}$	-0.014	-8.58 **
$\gamma_{kme,krd}$	0.002	1.86 *
$\gamma_{kme,l}$	0.009	2.24 **
$\gamma_{kme,oc}$	0.004	0.89
$\gamma_{krd,krd}$	-0.010	-11.78 **
$\gamma_{krd,ci}$	-0.027	-2.23 **
$\gamma_{krd,l}$	0.002	1.97 *
$\gamma_{krd,oc}$	0.034	2.9 **
$\gamma_{ci,kme}$	-0.024	-4.25 **
$\gamma_{ci,ci}$	0.152	17.99 **
$\gamma_{ci,l}$	-0.128	-20.54 **
$\gamma_{ci,oc}$	-0.431	-2.91 **
$\gamma_{l,l}$	0.034	10.06 **
$\gamma_{l,oc}$	-0.034	-10.06 **
$\gamma_{oc,oc}$	0.431	2.91 **
Cross-coefficients between output and factor prices		
$\gamma_{Q,kme}$	-0.001	-2.2 **
$\gamma_{Q,krd}$	-0.002	-5.19 **
$\gamma_{Q,ci}$	0.050	25.15 **
$\gamma_{Q,l}$	-0.035	-29.19 **
$\gamma_{Q,oc}$	-0.012	-7.12 **
Cross-coefficients between time trends and other variables		
ϕ_t	-0.033	-0.51
ϕ_{tt}	0.025	1.28
$\phi_{t,Pkme}$	0.001	0.78
$\phi_{t,Pkrd}$	-0.002	-2.03 **
$\phi_{t,Pci}$	-0.019	-5.8 **
$\phi_{t,Pl}$	0.007	3.6 **
$\phi_{t,Poc}$	0.013	4.42 **
$\phi_{t,Q}$	0.000	-0.08
constant	5.019	15.23 **
Number of observations	4029	
R-squared on cost equation	0.962	
RMSE	0.335	

kme = fixed machinery equipment, vehicles and structures investment; **krd** = R&D investment capital;

ci = intermediate consumption; **l**=labor; and **oc**=other costs; **Q** = gross real output; **t** = time

* **= coefficient significant at the 95 percent confidence level

* = coefficient significant at the 90 percent confidence level

For the translog cost function, the parameter γ_{ij} is intimately related to the elasticity of substitution and the factor shares. We define the cross-elasticity of substitution σ_{ij} as a measure of whether factors are substitutes or complements in production:

$$\sigma_{ij} = 1 + \gamma_{ij}/S_i S_j \text{ for all factor } i \neq j$$

and the own-price elasticity of substitution, σ_{ii} , as:

$$\sigma_{ii} = 1 + \gamma_{ii}/S_i^2 - 1/S_i \text{ for all } i$$

where S_i is equal to the share of expenditures of factor i in total factor costs. If i and j are substitutes (complements), an increase in the demand of one factor resulting from a change in its relative price will lead to a reduction (increase) in the demand of the other. In notation:

$$\begin{aligned} \text{If } \sigma_{ij} > 0, & \Rightarrow \text{factors } i \text{ and } j \text{ are substitutes} \\ \text{If } \sigma_{ij} < 0 & \Rightarrow \text{factors } i \text{ and } j \text{ are complements.} \end{aligned}$$

If it is found that any other factor of production is a complement to R&D demand, this would be positive as it would indirectly contribute to higher productivity. From here the demand elasticities are easy to derive (see Varian(2001):

$$\begin{aligned} \xi_{ii} &= S_i \sigma_{ii} & \text{own-price elasticity.} \\ \xi_{ij} &= S_j \sigma_{ij} & \text{cross-price elasticity} \end{aligned}$$

Based on the sign of the σ 's derived from the estimated coefficients, demand for R&D capital (denoted **Krd**) is a substitute for all other production factors in the Colombian manufacturing sector, with the exception of intermediate consumption (see Table 10).¹⁸ The substitution parameter between R&D investment and other machinery is large and positive ($\sigma_{krd,me} = 4.8$). The fact that R&D is such a strong substitute for machinery, equipment and structures suggests that a Colombian manufacturing firm that cannot buy the most modern version of a machine will tend to substitute for an older model. Likewise, the positive coefficient with labor could be interpreted as follows: when an experienced researcher cannot be found, firms will substitute for a possibly less experienced professional. Only the elasticities of substitution with respect to intermediate consumption come out consistently negative, implying complementarity: when more intermediate consumption is demanded, so are other factors.

¹⁸ Part of this may be due to the fact that specialty labor such as researchers, and specialty machines used in R&D processes are clearly substitutes for regular technical and professional labor and operational machines, respectively.

The results also suggest that a decline in the price of R&D inputs has a greater effect in the long run than in the short run, because it affects production growth positively. A lower R&D price leads to greater R&D investment and greater production, which then spurs greater production the following period. This is because the cross-coefficients with respect to real production, Q , are interpreted in a similar way to prices. The sign of $\gamma_{Q,krd}$ is negative and robust, which means that greater production leads to greater investment in R&D (the idea analyzed in the literature and mentioned earlier of “success engendering success”). This is a positive result, because it suggests that the return to R&D investment in Colombia likely becomes larger over time.¹⁹

Results According to Size and Innovative Capacity of the Firm

Table 10 shows the results when the sample is divided into two equal groups: large and small firms (using the median output to divide the sample, for every period). The results turn out robust and significant, in particular for large firms. The following conclusions can be derived from the econometric results:

Table 10. Estimated Elasticities of Substitution and Demand Among Factors, Full Sample

cross-factors	Substitution (σ)	demand-price (ξ)
krd,krd	-60.84	-1.42
		with itself
kme,kme	-78.55	-1.64
ci,ci	-0.64	-0.28
l,l	-3.1	-0.63
oc,oc	2.09	0.67
		with K_{rd}
kme,krd	4.78	0.11
krd,ci	-1.63	-0.04
krd,l	1.5	0.03
krd,oc	5.62	0.13
		with K_{me}
kme,krd	4.78	0.1
kme,l	3.01	0.06
kme,oc	1.53	0.03
ci,kme	-1.63	-0.03
		with l
ci,l	-0.45	-0.09
l,oc	0.47	0.1
		with ci
ci,oc	-2.11	-0.916

¹⁹ As mentioned earlier, we are not able to directly measure long-run elasticities to compare with the estimated short-run elasticities.

- The cross-price parameters (γ) of large versus small firms are generally similar, except that $\gamma_{krd,me}$ is statistically insignificant for the case of large firms, so we cannot infer the degree of substitutability between R&D and machinery for large firms alone. However, they are very strong substitutes for the case of small and medium sized firms (SMEs).
- The R&D price elasticity ξ_{krd} , for SMEs is somewhat larger than for large firms, as may be expected (substituting in the equation $\xi_{krd} = S_{krd} \sigma_{krd,krd}$): the estimated elasticity values for large firms and SMEs are -1.3 and -2, respectively. If SMEs' demand is more responsive to price, it suggests that they will respond more than large firms to fiscal incentives.
- $\gamma_{Q,krd}$ is large and highly significant for SMEs, implying that the greater the production, the more likely it is that there will be additional R&D investment in the future. For the case of large firms, this parameter is not statistically significant..
- Finally, the results suggest that SMEs become more efficient as their production scale increases. Define the coefficient of economies of scale as:

$$\theta(Q) = \alpha_Q + \sum_{i=1}^5 \gamma_{Qi} * \ln(P_i)$$

This coefficient, known as the “production scale elasticity”, measures the percentage increase in total costs for every 1 percent increase in production. If it is negative, it means there are increasing returns to scale because costs increase slower than production (see Segal(2002)). For the full sample and the sample of large firms, this coefficient is positive, implying decreasing returns to scale. In contrast, for SMEs, it is -0,51, negative, implying *increasing* returns to scale.²⁰

Innovation is also related to a higher elasticity of demand for R&D investment by firms.

Table 12 shows the results when the sample is divided into ‘more innovative’ and ‘less innovative’ firms. The full sample was ranked according to the share of R&D expenditures in total expenditures, and those above the median were compared to those below the median. The results are robust and most of the coefficients are significant. As can be expected, the coefficient shows that the innovative firms have a greater own price elasticity of R&D investment, and greater sensitivity of this investment relative to production. Therefore, innovative firms are likely to have a stronger positive response to R&D tax incentives.²¹

²⁰ However, the result seems to be true for firms that engage in some form of R&D. Other studies which considered longer periods have found that the Colombian manufacturing sector on average exhibits constant returns to scale (such as Fernández, A.M (2003) y Arbeláez, M.A y M.F. Rosales (2004)). The former study estimated production functions by sector for the period 1977-1991, while the second estimated production functions at the national level for the 1981-2001 period. In both studies the null hypothesis that there were constant returns to scale in manufacturing could not be rejected.

²¹ Note that the most innovative firms are not necessarily those that receive the tax incentives, as can be deduced from tables 7 and 8.

Table 11: Results of the Regression of System of Factor-costs Equations
 Estimated Parameter Values by Size
 Method: Panel SUR, 2000-2002

	large establishments		Rest of firms (SMEs)	
	parameter	Asymptotic t-statistic	parameter	Asymptotic t-statistic
Output coefficients				
α_Q	0.639	6.25 **	-0.548	-1.83 *
γ_{QQ}	0.021	3.44 **	0.099	4.49 **
Simple coefficient of the 5 factor prices				
α_{kme}	-0.042	-2.75 **	0.167	5.56 **
α_{krd}	-0.007	-0.68	0.142	6.24 **
α_{ci}	-0.193	-3.23 **	-0.683	-8.09 **
α_l	0.752	24.33 **	0.786	13.33 **
α_{oc}	0.490	10.14 **	0.589	7.13 **
Cross-coefficients of factor prices , where $\gamma_{ij} = \gamma_{ji}$				
$\gamma_{kme,kme}$	-0.013	-6.63 **	-0.014	-5.06 **
$\gamma_{kme,krd}$	0.001	0.81	0.004	2.31 **
$\gamma_{kme,l}$	0.012	5.75 **	-0.005	-0.62
$\gamma_{kme,oc}$	-0.090	-2.8 **	0.015	1.93 *
$\gamma_{krd,krd}$	-0.010	-10.49 **	-0.010	-5.8 **
$\gamma_{krd,ci}$	-0.054	-3.37 **	-0.012	-0.65
$\gamma_{krd,l}$	0.002	1.37	0.002	0.64
$\gamma_{krd,oc}$	0.062	3.88 **	0.020	1.1
$\gamma_{ci,kme}$	-0.017	-2.07 **	-0.028	-3.21 **
$\gamma_{ci,ci}$	0.386	5.29 **	0.189	12.8 **
$\gamma_{ci,l}$	-0.112	-14.94 **	-0.161	-13.79 **
$\gamma_{ci,oc}$	-0.258	-3.44 **	-0.420	-2.16 **
$\gamma_{l,l}$	0.028	7.9 **	0.057	7.1 **
$\gamma_{l,oc}$	-0.028	-7.9 **	-0.057	-7.1 **
$\gamma_{oc,oc}$	0.090	2.8 **	0.420	2.16 **
Cross-coefficients between output and factor prices				
$\gamma_{Q,kme}$	0.003	3.12 **	-0.011	-5.13 **
$\gamma_{Q,krd}$	0.001	1.17	-0.009	-5.55 **
$\gamma_{Q,ci}$	0.039	11.08 **	0.069	12 **
$\gamma_{Q,l}$	-0.034	-18.83 **	-0.036	-8.86 **
$\gamma_{Q,oc}$	-0.008	-2.75 **	-0.014	-2.42 **
Cross-coefficients between time trends and other variables				
Φ_t	-0.043	-0.44	-0.096	-0.49
Φ_{It}	0.025	1.13	0.064	1.82 *
$\Phi_{t,Pkme}$	0.002	1.57	-0.001	-0.67
$\Phi_{t,Pkrd}$	-0.004	-2.87 **	-0.001	-0.71
$\Phi_{t,Pci}$	-0.015	-3.31 **	-0.022	-4.28 **
$\Phi_{t,Pl}$	0.004	1.82 *	0.013	3.36 **
$\Phi_{t,Poc}$	0.012	3.22 **	0.012	2.38 **
$\Phi_{t,Q}$	-0.001	-0.16	-0.002	-0.11
constant	3.284	3.73 **	12.404	6.01 **
Number of observations	2402		1627	
R-squared on cost equation	0.95122		0.73637	
RMSE	0.274		0.403	

kme = fixed machinery equipment, vehicles and structures investment; **krd** = R&D investment capital;

ci = intermediate consumption; **l** = labor; and **oc** = other costs; **Q** = gross real output; **t** = time

* = coefficient significant at the 95 percent confidence level

* = coefficient significant at the 90 percent confidence level

1/ Where the gross output value was used as criteria to divide the sample

Table 12: Results of the Regression of System of Factor-costs Equations
 Estimated Parameter Values by Level of Innovation Method: Panel SUR, 2000-2002

	more innovative firms		Less innovative firms	
	parameter	Asymptotic t-statistic	parameter	Asymptotic t-statistic
Output coefficients				
α_Q	0.433	7.38 **	0.572	10.59 **
γ_{QQ}	0.030	8.11 **	0.025	7.36 **
Simple coefficient of the 5 factor prices				
α_{kme}	0.026	1.75	0.015	1.19
α_{krd}	0.067	5.83 **	0.009	2.68 **
α_{ci}	-0.321	-7.72 **	-0.345	-6.98 **
α_l	0.601	28.28 **	0.779	27 **
α_{oc}	0.627	16.05 **	0.543	12.9 **
Cross-coefficients of factor prices , where $\gamma_{ij} = \gamma_{ji}$				
$\gamma_{kme,kme}$	-0.004	-2.49 **	-0.009	-4.22 **
$\gamma_{kme,krd}$	0.004	2.49 **	0.000	0.63
$\gamma_{kme,l}$	-0.008	-3.12 **	0.011	2.32 **
$\gamma_{kme,oc}$	0.043	1.12	0.013	0.69
$\gamma_{krd,krd}$	-0.015	-7.81 **	-0.001	-1.52
$\gamma_{krd,ci}$	0.013	5.05 **	0.008	1.47
$\gamma_{krd,l}$	0.001	0.66	0.001	1.28
$\gamma_{krd,oc}$	-0.157	-5.15 **	-0.008	-1.53
$\gamma_{ci,kme}$	-0.010	-1.26	-0.015	-0.81
$\gamma_{ci,ci}$	0.268	4.52 **	0.267	4.45 **
$\gamma_{ci,l}$	-0.130	-17.31 **	-0.107	-11.72 **
$\gamma_{ci,oc}$	-0.128	-2.09 **	-0.160	-2.68 **
$\gamma_{l,l}$	0.008	3.12 **	0.025	5.17 **
$\gamma_{l,oc}$	0.226	4.64 **	-0.025	-5.17 **
$\gamma_{oc,oc}$	-0.113	-2 **	0.000	-1.17
Cross-coefficients between output and factor prices				
$\gamma_{Q,kme}$	0.000	0.32	0.000	-0.49
$\gamma_{Q,krd}$	-0.002	-3.55 **	0.000	-1.32
$\gamma_{Q,ci}$	0.045	18.06 **	0.052	17.05 **
$\gamma_{Q,l}$	-0.026	-18.54 **	-0.036	-20.61 **
$\gamma_{Q,oc}$	-0.017	-7.12 **	-0.015	-5.71 **
Cross-coefficients between time trends and other variables				
ϕ_t	-0.096	-0.97	0.102	1.27
ϕ_{tt}	0.056	1.81 *	0.014	0.61
$\phi_{t,Pkme}$	0.000	-0.01	-0.001	-0.64
$\phi_{t,Pkrd}$	0.000	0.4	0.001	1.21
$\phi_{t,Pci}$	-0.014	-3.25 **	-0.019	-3.83 **
$\phi_{t,Pl}$	0.005	1.84 *	0.005	1.79
$\phi_{t,Poc}$	0.009	2.19 **	0.014	3.26 **
$\phi_{t,Q}$	-0.001	-0.12	-0.007	-1.61
constant	5.504	11.59 **	3.727	8.46 **
Number of observations	1990		2039	
R-squared on cost equation	0.9566		0.9714	
RMSE	0.379		0.273	

kme = fixed machinery equipment, vehicles and structures investment; **krd** = R&D investment capital;

ci = intermediate consumption; **l** =labor; and **oc**=other costs; **Q** = gross real output; **t** = time

* = coefficient significant at the 95 percent confidence level

* = coefficient significant at the 90 percent confidence level

1/ Where the share of R&D expenditures in totals was used as the criteria for dividing the sample

C. Policy and Fiscal Implications of the Results on the Colombian R&D Tax Incentive System

Net Benefit of the Policy for the Government

The prior results show that the estimated price elasticities of R&D investment in Colombia is relatively high, at least compared to the average of roughly 0.5 found in other countries studied (mostly OECD countries). 14. first row shows that a fall in the R&D price of 1 percent, all else equal, increases investment by almost 1.416 percent, suggesting that a policy that can significantly reduce unit costs of R&D investment could have important implications for investment in manufacturing R&D.

Nevertheless, one has to first measure the full effect of the current incentive on R&D prices. A 1 peso increase in R&D tax incentives reduces the price of R&D, but by only 4 cents (centavos) (elasticity is -0,041). This occurs for two reasons. First, the size of the budget approved by Colciencias for deductions, on average, is a very small percentage of the total R&D expenditures of the average manufacturing firm in the sample—about 0.1 percent. Therefore, it affects a very small share of the R&D costs to the firm. Second, by permitting a deduction of 125 percent, in present value terms it is not much more generous than the accelerated depreciation allowance many firms already enjoy under current tax law. For example, under existing Colombian legislation, if an \$100 computer system can be fully depreciated over a 5-year period, in net present value terms this is equivalent to about \$73-worth of an immediate deduction, which is quite generous!

A measure of the total effect on R&D investment of a dollar foregone of government revenue due to the tax incentive is now derived. We multiply the total price elasticity by the tax/price elasticity (the calculation of the total price elasticity is described in annex 2). The result measures the effect of a 1 percent increase in R&D deduction on R&D investment. For our Colombian sample, it corresponds to:

$$\xi_{total} = \psi * \xi_{krd, krd} = (-0,041) * (-1,416) = 0.059$$

where ψ is defined as the effect of changes in tax incentives on additional R&D expenditure

$$\psi = \frac{\partial P_{kid}}{\partial u} * \frac{u}{P_{kid}} .$$

To assess whether the fiscal incentive was effective--from a cost-benefit

point of view--for the government, we compare the effective expenses on R&D during the period in question (2000-2002), with the tax expenditures of the government from the R&D deduction. Additional R&D expenditure can be obtained by multiplying the actual R&D capital expenditure by ξ_{total} , and the total is then compared with the revenue foregone by the government.

The real benefits of an R&D tax incentive are clear in principle. When a fiscal incentive is granted, the firm goes ahead and invests the budgeted amount subject to the deduction, but the deduction may also create an additional incentive for the firm to invest beyond that, which has a benefit for society. This additional incentive, if positive, is a measure of the success of the system. Studies of the Canadian system, for example, show that the fiscal incentive system for R&D promoted additional investment, despite its generosity. According to Shah (1995), a dollar of revenue foregone by the government of Canada between 1963 and 1983 created an additional \$1.80 of R&D investment in Canada.

Table 13: Direct and Indirect Effects of Tax Incentives on R&D Investment
Projections of the SUR Model

Effect	value
<i>Sensitivity of R&D Investment</i>	
income elasticity	
Partial R&D price elasticity	-1.416
Total R&D price elasticity	-1.416
Elasticidad of tax deduction on R&D investment quantity	0.059
Price/tax deduction elasticity	-0.041
<i>Effects on investment 2000-2002, in millions of current pesos</i>	
R&D expenditures of manufacturing firms according to DANE definition (source: DANE) (a)	2,874,069
in percent of GDP:	1.6%
R&D expenditures of firms which use R&D tax incentives (b)	8,507
Total spending on R&D and innovation in Colombia according to OCyT definition	1,045,981
of which: companies (c)	44,835
Total value of projects approved by Colciencias for tax R&D deductions	162,393
Approximate fiscal revenues foregone by government (tax expenditures) as a result of incentives	56,838
<i>Additional R&D investment for every peso of fiscal revenues foregone by government:</i>	
according to the total sample of manufacturing firms of DANE (a)	2.96
according to the sample of firms that received incentives (b)	0.05
according to OCyT, by firms (c)	0.05

Source: author's calculations, DANE and Observatorio Colombiano de Ciencia y Tecnología (OCyT), 2004

There are various ways to do the net benefit calculation for the Colombian case. If we calculate the additional R&D expenditures of firms that received Colciencias' fiscal incentives, it turns out that they invested only 5 additional cents for every dollar foregone by the government on these particular firms (table 14, second from last row). However, we need to consider firms outside of manufacturing that also received incentives. When we compare the cost for the government of the program in its entirety during those years to the additional R&D investment reported by Observatorio de Ciencia y Tecnología (OCyT), which includes educational institutions, (using the same elasticity), we also find a very similar 'return' to the government (table 14, last row). Firms invest 5 additional cents for every tax dollar foregone.

However, this does not mean that Colombian firms do not take advantage of R&D investment, but that the particular projects that Colciencias finances may not be the most productive.

A more liberal interpretation could be that the manufacturing sector as a whole benefits from investment in R&D, in particular those firms which do a fair amount of R&D investment, perhaps because of a spillover effect. We could, instead, define additional R&D spending of firms in the manufacturing sector according to DANE (and used in the regressions). The result is reported in the third to last row of table 13. Under this broader interpretation, the additional R&D investment in manufacturing for every dollar foregone is \$2.96. However, this rests on the very strong assumption that the R&D investment of manufacturing firms would not have occurred had the government not offered tax incentives to any firm, which is unlikely. We therefore consider that the former results of 5 cents on the dollar paints a more accurate picture of the short-term policy effect. Compared to the results of other studies reported by Sawyer (2005) in table 2, Colombia's system seem relatively less effective internationally. The results should also be qualified by the fact that so few firms receive R&D tax incentives. We look in more detail at the fiscal implications in what follows.

The Fiscal Implications of R&D Incentives

According to DIAN estimates, the tax expenditures (foregone income) from all tax incentives in Colombia in 2005 were equivalent to 0.9 percent of GDP, and our calculations show that fiscal incentives for R&D constitute 1.7 percent of all tax incentives (see table 3). So, they are barely 0.016 percent of GDP.²² If one considers that technological development should lead to greater GDP growth, it is clear that the program could be vastly expanded without causing a fiscal burden (see table 3). Indeed, they have many advantages over the other, more expensive incentives because: (i) R&D tax incentives are designed to correct an externality; (ii) they apply uniformly across all sectors of the economy (unlike most other fiscal incentives in Colombia); and (iii) are not as subject to fraud of false declaration (because of the strict application procedures that have been instituted by Colciencias).

Two other very popular tax incentives for firms in Colombia which offer much greater tax relief and are subject to less scrutiny also explain in part the low popularity of the R&D incentive. The tax reform of 2003 offered an immediate 30 percent temporary deduction for retained earnings if they are used to buy machinery and equipment. In addition, the machinery and equipment qualifies for accelerated depreciation, and in some cases reduced VAT rates. There is no limit to the amount the firm can deduct under the 30 percent

²² About 3 percent of that amount corresponds to the foregone revenue from the 16 percent VAT exemption.

deduction, unlike for the R&D deduction, where only pre-approved material R&D expenses are allowed.²³

D. Effects of the R&D Tax Incentives on the Demand for R&D Investment

Finally, we consider whether firms or entities that receive the R&D tax deduction tend to invest significantly more in R&D than other firms. This would be another measure of the success of the policy, if it can be determined that those firms became more productive the following period relative to firms that did not receive incentives. Using DANE's survey of manufacturing data, a simple factor demand equation was estimated using the method of panel generalized least squares. We include a dummy variable which takes the value 1 if the firm received a Colciencias tax deduction that year, and zero otherwise. The dependant variable measures real R&D investment by establishment, that is, R&D expenditure divided by its effective price, as defined earlier. Since the price is determined simultaneously with quantity demanded, a simple equation will exhibit multicollinearity. We therefore include a lagged R&D price variable as well as a control, lagged real production (Q_t), to take into account the effect that higher output could have on investment. We also include other variables that could affect real R&D investment, such as the number of professional and technical staff members as a percent of total, or the number of technical and professional staff engaged in R&D as a percent of the total. Annex 3 describes the variables and data.

The results confirm that a firm which receives an R&D tax deduction in Colombia is more likely, on average, to invest more in R&D than a firm that has not. Different equation specifications, presented in columns (a), (b) and (c) of Table 15, differ in terms of their inclusion or non-inclusion of labor shares. Nonetheless, in all cases the results are robust and all the coefficients statistically significant at the 95 percent level. Specifically, the coefficient on the dummy for the R&D tax incentives is positive and significant, confirming that the incentive leads to greater investment in R&D.

It should be noted, however, that with a panel of only three periods, caution has to be taken regarding the interpretation of the dynamic aspects of R&D investment.

²³ Recall that firms cannot take a deduction for the costs of remuneration for personnel working on the R&D project.

Table 14: Results of Regressions of Manufacturing Establishments, 2000-2002
Minimum Generalized Least Squares Method - Panel With Random Effects
Dependant Variable: Real R&D Investment (krd) 1/

Equations	(a)	(b)	(c)
Constant	-2.12 -5.33 **	-2.17 -5.45 **	-2.24 -5.62 **
Dummy fiscal incentive -- <i>Dummy_incentive</i>	1.09 2.23 **	1.07 2.19 **	1.04 2.13 **
Lagged log of the R&D price -- $\ln(P_{kid})_{-1}$	-0.54 -9.14 **	-0.52 -8.86 **	-0.53 -9.05 **
Lagged log of output -- $\ln(Qr)_{-1}$	0.88 35.02 **	0.89 35.81 **	0.89 35.92 **
Percentage of technical and skilled employees over total employees	1.21 2.78 **		
Percentage of employees engaged in R&D as a share of total employees			1.46 1.84 **
Number of observations	2278	2278	2278
R ²	0.46	0.45	0.45
Wald χ^2	1355.27	1337.49	1346.07
ρ	0.48	0.48	0.48

1/ asymptotic t-statistics in italics

* **= coefficient significant at the 95 percent confidence level

V. CONCLUSIONS

This paper analyzes the effect of the R&D tax incentives offered by Colciencias to Colombian firms since 2000 and its effect on R&D investment. Colombia is an interesting case because, unlike most other countries, the tight application process for the 125 percent income tax deduction on R&D expenditures rules out the possibility that firms may be claiming tax incentives for expenditures different from those defined under the law. The drawback, of course, is that the program is extremely limited.

As in many other Latin American countries, the public sector has historically benefited disproportionately more than the private sector from many of the science and technology promotion policies. Relative to OECD countries, the share of R&D expenditures to GDP in Colombia is small, and the amount financed by the private sector even smaller. While the application procedures for R&D tax deductions works relatively well, about half of the applications pertain to public or publicly affiliated institutions that use the process to gain the 'seal of approval' of the project. This defeats the purpose of the fiscal instrument, which is to mobilize private financing of R&D. Moreover, there is minimal dissemination and general knowledge regarding the existence of these incentives. Colciencias, which

administers the program, does not have formal ties with the tax revenue agency in Colombia (DIAN).

Moreover, the firms that apply and receive tax deductions tend to be large. Smaller firms (SMEs) that are more likely to be financially constrained are less likely to apply. However, the econometric and survey results show clearly that *it is the SMEs which are most likely to need and benefit from the R&D incentives* (in other words, they would raise their R&D investment more for every peso increase in tax incentives). The high short-run elasticity of demand for R&D investment estimated in the manufacturing sector indicates that, by international standards, SMEs in Colombia are very sensitive to effective R&D price changes, and the higher productivity that ensues from this investment leads to greater future investment later on, and even some improvement in scale economies as suggested by theory.

However, the Colombian system of fiscal incentives for R&D is too small, limited and not sufficiently well-targeted to lead to substantial increments in total R&D investment. The amount costs the government a mere 0.016 percent of GDP, and is limited to non-labor, specific, pre-approved research projects.

Some policy changes in this regard may be useful. A system of tax credits/subsidy, with the amount of the subsidy defined as a proportion of total R&D expenditures of the firm (and independent of the 35 percent income tax rate), could go a long way to increase R&D investment in Colombia. Moreover, the policy should be better disseminated and targeted towards smaller firms. Some incentives should be tied to programs which encourage research centers and universities to work together with the private sector (perhaps through generous matching of private sector funds when the project is joint between a firm and a researcher). This way, a private-sector-led growth in relevant, home-grown research and development can emerge.

In addition to that, the existing mechanisms can be made more effective. It is recommended that DIAN take the lead in administrative aspects of the fiscal incentives. For example, it could work jointly with Colciencias to coordinate the applications and to even simplify some of the paperwork, taking advantage of its existing infrastructure and processes. As the main tax authority, the DIAN should be in charge of providing information to taxpayers on this (for example, by including information in its Web page and at its taxpayer support branches).²⁴

Unless an expanded program can lead to a greater critical mass of domestically-generated projects, which generate new research and development in Colombia, it will be very difficult for the path of economic growth in Colombia to accelerate in the coming years.

²⁴ None of the DIAN offices handle these incentives directly, and many of them are unaware of the R&D incentives.

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Annex 1. Probit Analysis. Characteristics of Those Who Apply for the R&D Investment Deduction.

A Probit model is estimated to assess the probability that a firm will apply for the R&D tax deduction. The estimated model looks as follows:

$$\Pr(\text{applying} = 1) = \Phi \left(\beta_1 \text{finlimit} + \beta_2 \text{invRD} + \beta_3 \text{adeqinv} + \beta_4 \ln(\text{assets}) + \beta_5 \text{intel_assets} + \beta_6 \text{recur_D} \right)$$

where the dependant variable ‘*applying*’ takes the value 1 if the firm applied for the 125 percent R&D income tax deduction, and 0 otherwise. The independent variables are:

finlimit: corresponds to the response the firms gave in the Fedesarrollo survey regarding investment obstacles in R&D. The variable can take a dichotomous value of between 1 to 5. 1 indicates that the firm encounters major obstacles, and 5 indicates no obstacles. With this information we hope to capture whether firms that have greater financial limitations tend to apply more.

invRD: This variable corresponds to the share of R&D investment of the firm relative to total investment. The number was calculated using the results from the first question of the Fedesarrollo survey. This variable seeks to capture the relationship between the relative quantity of R&D and the probability of applying.

adeqinv: this variable was also constructed using the Fedesarrollo survey responses. It takes on the value of 4 if the firm responded that R&D investment levels are ‘adequate’, 3 if the response was ‘relatively adequate’, 2 if they responded ‘a little lower than what would be ideal’, and 1 if the firm responded that it was way below the desired level. The variable seeks to capture whether the firm’s perceptions regarding the level of R&D investment influenced the firm’s probability of applying for the tax deduction.

Ln(assets): is the logarithm of the firms’ assets as reported in their balance sheets to Colombia’s Superintendence of Corporations (*Superintendencia de Sociedades*, see <http://www.supersociedades.gov.co>). It is a proxy for firm’s size, and captures whether size affects the probability of applying.

Intel_assets: equals the share of ‘intellectual assets’ in total assets. It is the sum of the valuation of trademarks, patents, royalties, and know-how, as reported to *Superintendencia de Sociedades*. The variable seeks to capture whether firms that apply for the deduction already have some intellectual asset (and are thus more prone to investing in R&D).

Table 15: Probit Estimation: Probability of
Applying to R&D Tax Deduction

dependant variable: applying for tax deductions

	Coefficiente
<i>finlimit</i>	0.0335 (0,116)
<i>invRD</i>	0.0025 (0,006)
<i>adeqinv</i>	-0.1286 (0,179)
<i>ln(assets)</i>	0.1904 (0,094)***
<i>intel_assets</i>	-2.8165 (4,203)
<i>recur_D</i>	1.6214 (0,723)**
<i>constant</i>	-4.7202 (1,652)***
Number of obs.	152
LR (chi-2)	17.02
p-value	0.0092

Standard errors in parenthesis

*** significant at 1%, ** significant at 5%

Note: observations refer to firms

otra versión (other version)

Variable dependiente: Decisión_Renta	
	Coefficiente
limit_fin	-0.0092 (0,111)
inv_cyt	0.0023 (0,005)
inv_aprop	-0.1062 (0,175)
l_activos	0.2643 (0,090)***
activosintel_totact	-4.3045 (4,924)
constante	-5.8018 (1,617)***
Número de obs	152
LR (chi-2)	11.53
p-value	0.042

Errores estándar entre parentesis.

*** significativo al 1%

Recur_D: is a dummy variable which takes the value 1 for firms that have applied for the R&D deductions more than once, and 0 otherwise. This variable captures whether there is a tendency to apply more if you have applied before.

The results, presented in table 16, show that the only statistically significant variables are the size proxy, $\ln(\text{assets})$ and the repetition dummy, *recur_D*: the greater the size, the higher the probability of applying. Moreover, firms that have previously applied for the R&D deduction have a greater probability of applying again. None of the other variables turn out to be statistically significant. The estimations were also made using robust errors to correct for heteroskedasticity but the results were quite similar.

Annex 2. Estimation of the System of Cost and Demand Equations

With the objective of estimating firm-level data to evaluate the impact of the tax incentives, we take advantage of standard results of production theory, which allow the representation of production technology through the dual relation between cost and production and the use of flexible functional forms. According to Sheppard's lemma, if a firm minimizes costs and certain conditions are satisfied, specifically: (i) input prices are exogenous; (ii) the product transformation function $T(Q, X) = 0$, where Q denotes output and X denotes a vector of inputs, satisfies the usual regularity conditions, (which yields strictly convex isoquants); then there exists a dual cost function, $C(Q, P)$, where P is a price vector. This cost function is as good a representation of the firm's production technology as the product transformation function itself. Moreover, it satisfies the usual regularity conditions: C is nonnegative, differentiable, nondecreasing, linearly homogeneous and concave on P for a fixed nonnegative output; C is strictly positive for nonzero output, and Q is strictly increasing in Q .

For well-behaved relationships, one can deduce the structure of production technology directly from the cost function. The advantage is that one does not need to make any *a priori* restrictions on the production function.

To derive the input demands, we use a cost-minimization approach, which implicitly assumes that entrepreneurs make decisions on factor use, given exogenous prices. This makes the factor levels endogenous decision variables. Moreover, the scale elasticity can be obtained directly from the cost function; cost functions are homogeneous in prices regardless of the properties of homogeneity in the production function; and prices are likely to be less collinear than inputs.

Moreover, because capital is a fixed factor subject to adjustment costs every period, we do not adjust instantaneously to the desired level of the capital stock. Therefore, capital is considered a quasi-fixed factor, in particular R&D capital. The effective price is thus the user cost of capital. In contrast, inputs such as labor and intermediate costs can be adjusted instantaneously to the desired level, and so are considered variable factors.

Following Shah(1995) we assume a translog production function, which is easier to handle than other functional forms. Under the duality theory, this could be characterized as a nonhomothetic translog cost function.

A21. Model

We define 5 factors of production, i:

- **Kme**: physical capital, consisting of machinery and equipment, office equipment, transport equipment, buildings, structures and other nonresidential construction;

- **Krd**: R&D capital, made up of 6 sub-factors: (i) machinery and equipment used in modernization; (ii) lab equipment and other specialty items used for innovation; (iii) new information and communications technologies; (iv) training and technical assistance for skilled workers; (v) quality control, securing and certification expenditures; and (vi) new technologies developed by the establishment proper. This follows the definition of DANE's *Survey of Manufacturing, science and technology module*;
- **Ci**: Intermediate consumption made up of the consumption of raw materials and the purchase of electrical energy.
- **L**: total employed labor
- **Oc**: other costs, corresponding to operational and non-operational acquisitions of land such as rentals, administration, advertising and marketing, and all others.

The translog production function $C(Q, P; t)$ is described in equation 1 and rewritten here:

$$\begin{aligned}
 C = & \alpha_0 + \alpha_Q \ln Q + \frac{1}{2} \gamma_{QQ} \ln Q^2 \\
 & + \sum_{i=1}^5 \alpha_i \ln P_i + \frac{1}{2} \sum_{i=1}^5 \sum_{j=1}^5 \gamma_{ij} \ln P_i \ln P_j \\
 & + \sum_{i=1}^5 \gamma_{QP_i} \ln Q \ln P_i \\
 & + \phi_t t + \frac{1}{2} \phi_{tt} t^2 \\
 & + \sum_{i=1}^5 \phi_{tP_i} t \ln P_i + \phi_{tQ} t \ln Q + \varepsilon
 \end{aligned} \tag{3}$$

Where

P_i = price of input i , where $i = kme, krd, ci, l, oc$

Q = the value of production

t = technical change, proxied by a time trend

The coefficients represent the parameters to be estimated. Logarithmically differentiating this function with respect to input prices and applying Sheppard's lemma means that $\frac{\partial C}{\partial P_i} = X_i$

where X_i = quantity demanded of input i

The derived-demand equations obtained from the process can be written as:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{P_i X_i}{C} = S_i = \alpha_i + \sum_{j=1}^5 \gamma_{ij} \ln P_j + \gamma_{QP_i} \ln Q + \phi_{tP_i} t \tag{4}$$

where S_i is the share of the i th input in total cost. When estimating the parameters we can use certain conditions, which enter as restrictions, to solve for the coefficients. Namely, a “well-behaved” cost function must satisfy the following conditions (see Shah (1995) and Varian (2001)):

- Hicks-Samuelson symmetry conditions:

$$\gamma_{ij} = \gamma_{ji} \quad (\text{“Slutsky symmetry”})$$

- Zero homogeneity in prices: when all factor prices are doubled, the total cost will double. It can be shown that linear homogeneity implies the following restrictions:

$$\sum_{i=1}^5 \alpha_i = 1 \quad \sum_{i=1}^5 \gamma_{ij} = 0 \quad \sum_{i=1}^5 \gamma_{ji} = 0 \quad \sum_{i=1}^5 \gamma_{QP_i} = 0 \quad \sum_{i=1}^5 \gamma_{iP_i} = 0 \quad \text{for all factors } i, j.$$

- Monotonicity: the function must be an increasing function of input prices that is:

$$\frac{\partial \ln C}{\partial \ln P_i} \geq 0, \quad i = kme, krd, ci, l, oc$$

Because of the homogeneity constraint, only 4 of the five factor share equations above are linearly independent and can be estimated simultaneously. We therefore eliminate the equation that determines *oc*, i.e., the demand for other costs. This leaves a system of five equations: the translog production function (equation (1), and four demand-share equations as in (2)) above, where $i = \{Krd, Kme, l, ci\}$. These are estimated using Arnold Zellner’s seemingly unrelated regressions technique (SUR), using the econometric package STATA.

Once the parameters of the system of equations are estimated, we can obtain the elasticities of substitution of the different inputs, as well as the own-price elasticities and cross-price elasticities of factor demands. This allows us to analyze the existing relations between the productive factors

The elasticity of substitution σ_{ij} is formally defined as the percent change in the relative amounts of factors **j over i** resulting from a one percentage point change in the relative price of the same factors, denoted P_i/P_j . In a model of two inputs, the elasticity of substitution can only reflect two types of relations: substitutability or complementarity. The factors i and j are considered substitutes (complements) if, as a result of a fall in the relative price (P_i/P_j), the share of j to i (**j/i**) falls (rises) because there is greater (less) consumption of factor i relative to j. The elasticity of substitution can be obtained from the estimated parameters if one considers that:

$$\sigma_{ij} = \frac{\sum_{i=1}^5 P_i X_i}{X_i X_j} * \frac{\partial^2 C}{\partial P_i \partial P_j} = \frac{C}{X_i X_j} * \frac{\partial^2 C}{\partial P_i \partial P_j}$$

For the translog cost function, the elasticity can be obtained by taking derivatives with respect to P_i and P_j and substituting for the estimated parameter γ_{ij} :

$$\sigma_{ij} = 1 + \frac{\gamma_{ij}}{S_i S_j} \quad \text{for all } i \text{ and } j, \text{ where } i \neq j, \text{ and}$$

$$\sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} \quad \text{for all } i.$$

The price elasticities of input demands with respect to both own and other prices are also derived from the estimated γ_{ij} . The concept of elasticity of substitution and price elasticity are closely related. For the translog cost function, the cross-price elasticity is $\xi_{ij} = S_j \sigma_{ij}$ and the own-price elasticity is $\xi_{ii} = S_i \sigma_{ii}$.

A2.2 The Data

The estimations used data from the Annual Survey of Manufacturers (EAM) of DANE at the level of industrial establishment. The price information correspond to the most disaggregated producer price indices (PPI) calculated by the Banco de la República, the Colombian monetary authority.

Within the EAM, data on: costs, operating and non-operating expenditures, employees, changes in fixed assets, and most importantly, most of the information contained on the annex on technological innovation initiated in 2000. The estimations spanned the 2000-2002 period. Initially the panel had 19,889 observations, but the establishments that had not responded to the annex on technological innovation were eliminated, as well as those that reported no employees. Thus, the final panel has 5,274 observations. The following data were used to construct the variables:

Total annual cost (C) corresponds to the sum of expenditures on employee remunerations, other costs and operational expenditures and the purchases and net transfers of fixed assets.

Output (Q) is the value of gross production deflated by the PPI at the SITC-3 digit level depending on the principal activity of the establishment.

Value of physical capital (kme) consists of purchases of machinery and equipment, office equipment and computers, transport equipment, buildings and structures (including those under construction). Its price (p_{kme}) corresponds to the weighted average of the user costs of capital of each component, which was calculated as follows:

$$P_{kme} = \sum_{i=1}^5 \omega_i * q_i * (r + \delta_i) * (1 - u)$$

where:

i = type of capital **Kme** , consisting of: (1) machinery and equipment; (2) office equipment and computers; (3) transport equipment; (4) buildings; and (5) structures (including those under construction);

q = producer price index of capital goods at the SITC 3-digit level for each of the three types of capital goods. For machinery and equipment, it corresponds to the geometric mean of the following categories: production of general-purpose machinery; production of special-use machinery; production of domestic appliances not elsewhere specified; production of motors, generators and transformers; production of apparatus to be used for the distribution and control of electric energy; and production of other types of electrical equipment not elsewhere specified. The price index for office equipment and computers was calculated as the geometric mean of the production of office machinery, systems and accounting tools, and the production of office furniture. The price index for transport equipment was calculated as the geometric mean of the price of the production of automobiles, its motors, automotive parts; automotive vehicles trucks and carrier vehicles; and the production of other automotive vehicles not elsewhere specified. The price of buildings and structures was constructed using the price index for structures and buildings calculated by DANE and used by the *Titularizadora de Colombia* (which backs mortgages). We used the category for offices, commercial space and warehouses--which seemed like the prices relevant for industry--and calculated the geometric average. Finally, for the price of buildings under construction we utilized the PPI corresponding to construction materials.

δ = depreciation rate. We assume the following values: 0.14 for machinery and equipment, 0.22 for office machinery and computers, 0.3 for transport equipment and 0.03 for buildings, structures and ongoing construction. These are typical values used in many cross-country studies; and

u = income tax rate, which was equal to 35 percent during the 2000-2002 period.

l = total employment in the establishment. We used the costs and expenditures on all occupied employees. Its price (p_l) was the unit labor cost for each establishment, calculated as: (*total labor costs / number of employees*), normalized by the industrial average for the corresponding year.

ci = intermediate consumption consists of the consumption of raw materials and the purchase of electricity. Its price (p_{ci}) was constructed as the average PPI of intermediate consumption and of the median tariff charged to industrial firms by the electricity company (pesos per KWH). The source was the Energy and Gas Regulatory Commission (*Comisión de Regulación de Energía y Gas*.)

The value of research and development (R&D) capital (value of krd) corresponds to the total technological innovation expenditures reported by each establishment in Annex III of the EAM. It consists of six sub-components:²⁵

- i. Machinery and equipment used in modernization (upgrading);
- ii. Laboratory equipment and other special equipment used in innovative activities;
- iii. New information and telecommunications technologies;
- iv. Technical assistance and training on new technologies for workers;
- v. Expenditures on quality control, quality assurance, etc.; and
- vi. Expenditures in technologies developed internally by the establishment.

P_{krd} = the price of R&D capital. It was calculated as the weighted average of the prices of each of the 6 components, taking into account that the first three are quasi-fixed factors and the last three are variable factors. Furthermore, the calculation of this price also has to take into account the deductions firms that have used the R&D fiscal incentives can make:

$$P_{kid} = \sum_{i=1}^3 \omega_i \left\{ (1-s_n) (q_i (r + \delta_i) (1-u)) + s_i (q_i (r + \delta_i) (1-u(1+z))) \right\} + \sum_{i=4}^6 \omega_i \left\{ (1-s_n) * p_i + s_n * p_i * (1-uz) \right\}$$

Where:

i = the six R&D components listed above; and

s_n = budgeted value of the R&D project approved by Colciencias to receive the deduction divided by the total R&D expenditures (that is, expenditures on technology and innovation). In other words, it is the share of expenditures in krd subject to the R&D investment

²⁵ With the purpose of ensuring that there was no double-counting, each of these components was subtracted from one of the elements of total costs. the first and second components were subtracted from the value of machinery and equipment purchases, the third was subtracted from purchases of office machinery and computers; the fourth was subtracted from labor costs; and the last two were subtracted from the category other costs (*oc*), and so on.

deduction. The variable takes on positive values for firms that received the deduction in a particular year, and zero otherwise.

q = price index of the three fixed sub-factors/components of *krd*. For machinery and equipment used in modernization (upgrading), we used the same price index used general machinery and equipment previously described. For laboratory equipment and other special equipment, we used the PPI of the sub category ‘laboratory equipment, and other medical, optical and precision instruments’; For new information and telecommunications technologies, we used the PPI of the category of ‘radio and television equipment and telecommunications apparatus’.

δ = depreciation rate: 0.14 para machinery and equipment used in modernization; and 0.22 for lab equipment and other special equipment used in innovation, and new information and communications technologies.

p = Price of the variable sub factors/components of *krd*. For technical assistance and training on new technologies for workers we used the unit labor cost of professionals, technicians and technological employees for that particular establishment, normalized by the average unit labor cost of this category for the industry for the corresponding year. For expenditures on *quality control, quality assurance and standards* and expenditures on *technologies developed internally by the establishment*, we used the average PPI for the manufacturing industry, as no other more specific price index was available.

z = deduction above and beyond a write-off, for Colombia equal to 25 percent.

The value of the rest of the inputs used by the firm (denoted as *oc*= other costs) is calculated as the residual. It thus corresponds to the total cost minus: (i) purchases of physical capital (already subtracted from the corresponding innovation expenditure categories); (ii) labor costs (also subtracted from the components of R&D expenditure that include labor); (iii) intermediate consumption; and total R&D expenditures as defined above. Then we added to this total purchases of land. The price of ‘other costs’ (denoted p_{oc}) was calculated as the weighted average of the manufacturing industry’s PPI and the cost of capital for land. This latter cost of capital was constructed using the price for buildings and structures but with a depreciation rate of 0.03. This last category was included in *oc* because it constituted a very small percentage of total expenditures for those establishments that were incurring the costs; while most establishments did not acquire buildings. Like administrative costs, it is not as directly related to the production process.

A2.3 Calculation of the Additional R&D Expenditures for Every Peso the Government Foregoes on R&D Tax Incentives

The estimated parameters from the system of equations also allows us to calculate the estimated partial and total factor demand elasticities. The partial elasticity can be denoted as:

$$\xi_{kid,kid}^c = S_{kid} \sigma_{kid,kid} = \frac{(\gamma_{kid,kid} + S_{kid}^2 - S_{kid})}{S_{kid}}$$

The total own-price elasticity, taking account of indirect effects, can be expressed as:

$$\xi_{kid,kid} = \varepsilon_{kid,kid}^c + \frac{\partial X_{kid}}{\partial Q} * \frac{P_Q}{X_{kid}} * S_{kid}$$

Finally, to obtain the effect of changes in tax incentives on additional R&D expenditure (denoted ψ), it is necessary to estimate the elasticity of the R&D user cost of capital with respect to the tax rate (u).

$$\psi = \frac{\partial P_{kid}}{\partial u} * \frac{u}{P_{kid}} \quad (3)$$

To obtain the additional expenditure on R&D, one multiplies the government's tax expenditures from R&D by ψ y $\xi_{kid,kid}$. Table 14 of section IV shows the results.

Annex 3. Data for Estimation Presented in Table 15

The equation specification of the panel regression presented in table 15 is as follows:

$$Kid_{it} = \beta_0 + \beta_1 dummy_incentivo + \beta_2 \ln pkid_{t-1} + \beta_3 \ln Q_{t-1} + \beta_4 OcupPT_OcupTot + v_i + \varepsilon_{it} D$$

where:

Krd = is the ‘real’ amount of R&D investment per establishment. It is calculated as the total R&D expenditures divided by its (composite) price. ***P_{krd}***.

Dummy_incentive = is a dummy variable that takes the value 1 if the establishment has received an R&D tax deduction from Colciencias, and 0 otherwise.

$\ln(p_{krd})$ = natural log of the effective price of R&D capital. In the equation it is lagged once to avoid multicollinearity.

$\ln Q$ = natural log of gross output of the establishment, with one lag.

A variable representing technical, professionals and technology workers employed in the establishment as a percent of total employees was included. This variable was also replaced taking the workers employed specifically in R&D activities as a percent of the total.

v_i = random error component for establishment *i*

ε_{it} = total error component (includes the idiosyncratic error for each establishment-year).

The model was estimated using generalized least squares with random effects using STATA.