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How has the Portuguese innovation capability evolved? Estimating a time series of the stock of technological knowledge (1960–2001)

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Abstract

The importance of promoting innovation has been elevated up to a status of official standard since the Lisbon European Summit in 2000. Here research and development (R&D) has been singled out as an essential element of the foundation on which innovation could be built. R&D has been a growing area of investigation namely at level of firms micro studies aimed at uncovering firms' innovation capability. At the macro level, the relevance of R&D for countries' innovation capability has been, in a dynamic perspective, more often presumed rather than effectively tested. This latter limitation is, to a large extent, explained by the paucity of aggregated continuous time series on innovation indicators specifically those based on R&D expenditures. This paper aims at filling this gap by providing an estimate of the Portuguese innovation capability over the two last four decades based on the accumulated R&D efforts. Such indicator, albeit preliminary, will desirably endorse new investigation on the Portuguese catching-up process and, in this way, might inform present and future public programs related to R&D policies in particular and innovation policies in general.

Keywords

innovation
R&D expenditures
measurement
economic growth
JEL-Classification: O31; O32; C19; O40

Introduction

In the March 2000 European Summit held at Lisbon, the strategic goal for Europe to become the most competitive and dynamic knowledge-based economy in the world over the next ten years it was put forward. Moreover, the importance of promoting innovation and singled out research as an essential element of the foundation on which innovation can be built was highlighted. In a knowledge-based economy Research, Development and Innovation are essential to the development of new products and processes, which in turn are critical to economic competitiveness, employment and the enhancement of society (OECD 1992).

The Lisbon Strategy adopted an open coordination method, resorting to the use of qualitative and quantitative indicators, as an instrument to evaluate each country's performance and to spread information on best practices (Tavares 2003). These indicators do not measure adequately the efforts of structural reforms as they have essentially a static nature. Thus, to some extent, they miss the evaluation of the catching up effort. Therefore, it is desirable to consider dynamic indicators, which might provide more comprehensive representation of countries' effort.

Recent studies within new growth literature agreed that an economy's productivity level depends on its cumulative R&D effort and on its effective stock of knowledge, with the two being interrelated (Coe and Helpman 1993; Bönte 2003). For them innovation feeds on knowledge which results from cumulative R&D experience on the one hand, and it contributes to the stock of knowledge on the other.

Although there has been some progress in modelling knowledge at the theoretical level, less progress has been made at the empirical level (Aghion and Howit 1998). We do not have generally accepted empirical measures of such key theoretical concepts as the stock of (technological) knowledge and the stock of human capital (Teixeira 2005).

This paper aims at providing a dynamic indicator of Portugal's stock of technological knowledge or innovation capability over four decades (1960–2001), based on R&D accumulated efforts. This, combined with other quantitative and qualitative indicators, is likely to provide a broader and accurate depiction of country's economic evolution.

The paper is structured as follows. In the next section (Section 2), a brief review of the significance of R&D efforts for nations' economic performance is documented. Then, in Section 3, the methodology for constructing the proxy for indigenous innovation capability is detailed and the results of estimation presented. Finally, Section 4 presents the most important conclusions. The appendix presents all steps and results of the estimation procedure.

The importance of technological knowledge stock for economic performance: a review

Early neoclassical models (e.g., Solow 1956) treated technical change as an exogenous variable, illustrating how long-run economic growth only depended on (exogenous) technical change. Arrow (1962), who endogeneised technology by assuming learning-by-doing, argued that it grew at a constant rate, and found that long-run growth vitally depends on population growth. Other important contributions in the 1960s were made by authors such as Uzawa (1965), Phelps (1966), Conlisk (1967) and Shell (1967), who related technology growth to some specification based on labour resources devoted to the development of new technologies and ideas.

Albeit physical capital stock has been for long considered as an important generator of returns and growth (Levine and Renelt 1992), Hall and Hayashi (1989) underline that other forms of capital, such as knowledge or R&D capital (the accumulated know-how, technical expertise, trade secrets, etc., that are embodied, for instance in firms and the workforce) were also capable of generating high returns and could be more likely to generate more long-lasting, supra normal returns. In fact, the bulk of studies, mostly focusing North-American R&D, at both firm and industry levels do show high rates of return, around 25 and 15 per cent, respectively (Nadiri 1993).

Research on endogenous economic growth (Grossman and Helpman 1991; Romer 1990; Aghion and Howitt 1998) considers commercially oriented innovation efforts that respond to economic incentives as a major engine of technological progress and productivity growth. For such stream of the literature, innovation feeds on knowledge that results from cumulative R&D experience on the one hand, and it contributes to this stock of knowledge on the other. Therefore, an economy's productivity level depends on its cumulative R&D effort and on its effective stock of knowledge, with the two being interrelated (Coe and Helpman 1993).

Indigenous R&D produces traded and non-traded goods and services that bring about more effective use of existing resources and thereby raises a country's productivity level (Jones and Williams 1999). Additionally, domestic R&D enhances a country's benefits from foreign technical advances, and the better a country takes advantage of technological advances from the rest of the world the more productive it becomes (Coe, Helpman and Hoffmaister 1997).

The cumulative R&D effort is therefore intimately related to national innovative capacity of a country to produce and commercialise a flow of innovative technology over the long term (Stern, Porter and Furman 2000). Innovative capacity depends on an interrelated set of investments, policies and resource commitments, which underpin the production of the new-to-the-world technologies. National innovative capacity is not the realised level of innovative output at a single point in time but reflects the more fundamental determinants of the innovation process. This concept draws heavily on ideas-driven endogenous growth theory (Romer 1990, 1993). In models of ideas-driven growth, the ideas production function depends on two aggregate factors that influence the rate of innovation in an economy: the prior stock of knowledge accumulated by that economy, and the level of R&D effort devoted towards ideas production.

The theoretical framework described above highlights the potential importance of R&D for a country innovation capability and growth performance. The comprehensive study of Stern, Porter and Furman (2000) suggests that public policy plays an important role in shaping a country's national innovative capacity. Besides simply increasing the level of R&D resources available to the economy, government actions play an important role in shaping human capital investment and innovation incentives. They point that countries such as Japan, Sweden, Finland and Germany, who implemented policies aimed at encouraging human capital investment in science and engineering as well as competition on the basis of innovation (e.g., through the adoption of R&D tax credits), increased their level of innovative capacity over the last quarter century.

Nowadays, there exists convincing empirical evidence, which shows that cumulative indigenous R&D effort is in fact an important determinant of country's productivity and growth performance (Griliches 1988; Coe and Moghadam 1993; Teixeira and Fortuna, 2004).[1]

1 Soete (1996), Young (1998) and de Loo and Soete (1999) argue, however, that R&D efforts may have become more and more devoted to product differentiation than to (product or) process innovation, thus hardly affecting economic growth but more so total consumers' welfare.

The stock of technological knowledge as proxy for indigenous innovation capability: methodological underpins

Progress in modelling knowledge at the empirical level has been more slowly than that experienced at the theoretical level. 'To some extent the situation is one of the theory before measurement . . .' (Aghion and Howit 1998: 435). Few widely accepted empirical measures of the stock of (technological) knowledge and the stock of human capital (Teixeira 2005) exist. Most of them are only available at cross-country level hampering long-term economic growth analysis of individual countries, given the absence of continuous time series.

The stock of technological knowledge has been proxied by several variables, number of scientists and engineers (Jones 1993; Kortum 1994), patents (Fagerberg 1987, 1988; Kortum 1993, 1994), R&D intensity, that is, R&D/GDP ratio (Griliches 1988) and accumulated expenditures in R&D (Coe and Helpman, 1993; Coe, Helpman and Hoffmaister 1997).

Fagerberg (1987) divides technological levels and technological activities measures into two types: technological input measures (education expenditures, R&D expenditures, scientists and engineer employment), and technological output measures (patents). The former are directly related to countries' innovation capability, being also linked with countries imitation capability in the sense that a given scientific base is needed for imitation process to be well succeeded. The output measures are specifically related to innovative activities, that is, product and process innovation.

Interest in R&D depends more on the new knowledge and innovations and the economic and social effects that result than on the activity itself. Unfortunately, while indicators of R&D output are clearly needed to complement input statistics, they are far more difficult to define and produce. In the present work we privilege technological input measures, specifically, R&D accumulated expenditures. This option, besides the availability of data, is intimately related to the fact that the Portuguese economic growth process has been characterised, in larger extent, by the adoption and diffusion of knowledge and lesser by its creation (Verspagen 1993).

Analogous to Coe and Helpman's (1993) empirical work, we use R&D accumulated expenditures as proxy for the stock of knowledge (indigenous innovation capability). Thus, we estimate, for Portugal, a proxy of the internal or indigenous stock of knowledge based on internal expenditures of R&D.

The estimates R&D capital stocks were constructed on the basis of R&D data published by the Observatório de Ciência e Ensino Superior (OCES), former Junta Nacional de Investigação Científica (JNICT) and the Instituto Nacional de Estatística (INE).

We opt to construct two capital stocks, Total R&D capital stock – R&D performed by the whole economy, Firms, the State and Tertiary Education Non-profit Organisations – and Firm R&D capital stock (including only Firms). The reason relates to the fact that the meaning of the two aforementioned measures is likely to be substantially different for the purpose of assessing their contribution for countries' economic growth. Firm R&D

capital stock tends to be more intimately linked to market incentives while Total R&D capital stock, being more encompassing, tends to include knowledge spillovers from R&D activity, which are likely to positively affect the whole society.

At the present time, R&D statistics are the result of the systematic development of surveys based on the Frascati Manual and are part of the statistical system of the OECD member countries. According to Frascati Manual (OCDE 2002: 31), 'Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications'.

R&D covers three activities, basic research, applied research and experimental development (OECD 2002). Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective. Experimental development is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed. R&D covers both formal R&D in R&D units and informal or occasional R&D in other units.

In this vein, as highlight in the previous section, R&D activities emerge as key factor for building countries' innovation and technological adoption capabilities.

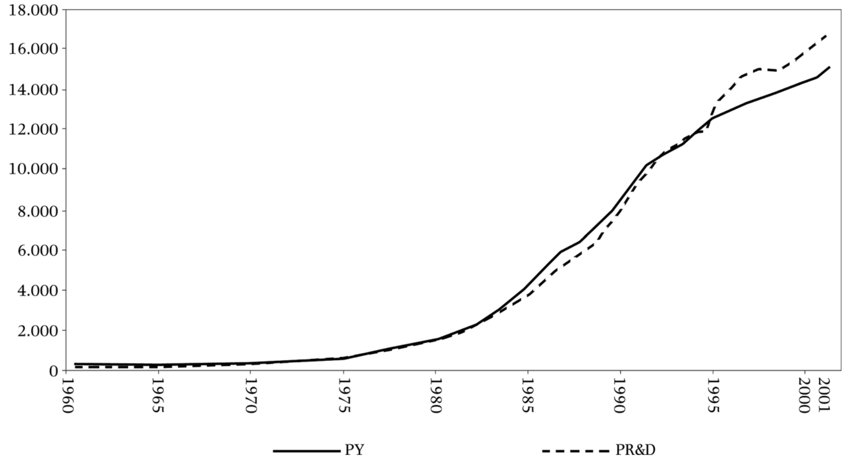
Research and development is an investment flow. However, what affects output is most probably some accumulated stock of the previous results of such investments. Since such results are not easily quantifiable; most authors have constructed some stock of R&D capital measure (Griliches 1980; Coe and Helpman 1993; Coe, Helpman and Hoffmaister 1997). Real R&D expenditures result from deflating nominal expenditures. For this purpose, we considered two deflators: GDP deflator (used by OCES and INE) and an index of R&D implicit prices.

The index of R&D implicit prices (PR&D) was constructed, following Coe and Helpman's (1993) suggestion, as a weighted average of GDP deflator (P_Y) and the index of workers average wages (P_W). However, differently from Coe and Helpman (1993), we take into account the effective composition of R&D expenditures. According to available data for the period 1964–2001, 60.03 per cent of total R&D expenditures corresponded to labour costs (see Table A3 in the Appendix).

Thus, the index of R&D implicit prices (PR&D)[2] was computed as follows (see Figure 1):

$$P_{R\&D} = 0.3997 \cdot P_Y + 0.6003 \cdot P_W \quad (1)$$

2 See Table A4 in the Appendix.



Source: Author's own calculations.

Figure 1: GDP deflator (P_Y) and an index of R&D implicit prices (PR&D), Portugal 1960–2001.

	Total R&D Investment	Firm R&D Investment
1964–1971	8.1	9.0
1971–1976	−6.3	−12.2
1976–1980	13.2	22.2
1980–1986	8.4	6.8
1986–1990	10.9	10.7
1990–1995	2.3	−2.2
1995–2001	9.9	18.2

Sources: 1964–72: JNICT (1986), Indicadores de Ciência e Tecnologia Portugal 1964–1982.
1976–90: INE, Anuário Estatístico do INE.
1990–2001: INE e Observatório da Ciência e Ensino Superior.

Table 1: Average real growth rates (in per cent) of the Portuguese Total and Firm R&D investment.

In spite of the two real R&D series do not significantly differ over the period in analysis (after 1995, though, their evolution is dissimilar), we opt by the index of R&D implicit prices as it is the most theoretical sound procedure.

Firm real R&D investment reveals a more erratic trend than total real R&D investment, suffering in the two most problematic periods of the Portuguese recent economic history, 1971–1976 and 1990–1995, a significant drop. This might be explained, in some extent, by the fact that the large energy price shocks, the resulting fluctuations in capacity utilisation, the substantial increase in uncertainty about the future absolute and relative prices may have forced many firms away from their long-run investment plans. Most recently, however, investment in R&D invigorated showing signs of considerable dynamism, with average annual rates of 9.9 and 18.2 per cent, respectively for the total economy and for firms (see Table 1).

R&D data are not available for all the years of the period 1960–2001. Therefore, in order to obtain a time continuous series, we use a specification relating real R&D expenditures to real product and investment (all in logs) to 'predict' the missing R&D data.[3] The outcome of such estimation is presented in Table A6 of the Appendix.

R&D total/firm capital stock (RTR&D/RFR&D), which are defined as beginning of period stocks, are computed from real R&D expenditures following a perpetual inventory method:

$$\text{RTR\&D}_t = (1 - \delta)\text{RTR\&D}_{t-1} + \text{RR\&D}_t, \qquad (2)$$

where $\text{RTR\&D}_t$ is the total R&D capital stock, in period t; $\text{RR\&D}_t$ is the real expenditure in R&D, in period t; and δ the rate of depreciation or knowledge obsolescence rate.

The benchmark for R&D capital stock (RTR&D0 or RFR&D0) is computed following the procedure suggested by Griliches (1980), as

$$\text{RTR\&D}_0 = \frac{\text{RR\&D}_0}{g+\delta}, \qquad (3)$$

where g is the real average annual growth rate of R&D expenditures over the period for which published R&D data were available (1964–2001); RR&D0 is the real expenditure in the first year for which published R&D data were available (1964), and δ is the depreciation rate.

The depreciation of R&D is related to the loss of quasi-rents in the sense that the information generated by this activity becomes widely disseminated (Bosworth and Jobome 2003).[4] Given the absence of empirical studies that indicate the approximate rate of knowledge diffusion, that is, the rate of knowledge obsolescence, we consider different rates of knowledge obsolescence (0, 5, 10 and 15%).[5]

As we can observe in Figure 2, the evolution of R&D capital stocks associated with different obsolescence rates are similar, therefore the choice for one or another rate was not consider highly fundamental for the purpose of the analysis. We opt to consider an intermediate depreciation rate, 5 per cent.

Between 1960 and 2001 the Portuguese R&D capital stock increased significantly, as the following figure shows. For the economy as whole (Total R&D capital stock) it increased by a factor of 10.5. Considering the private sector (Firms R&D capital stock) this stock was 13-fold larger by the end of the period than at the beginning (see Figures 3 and 4).

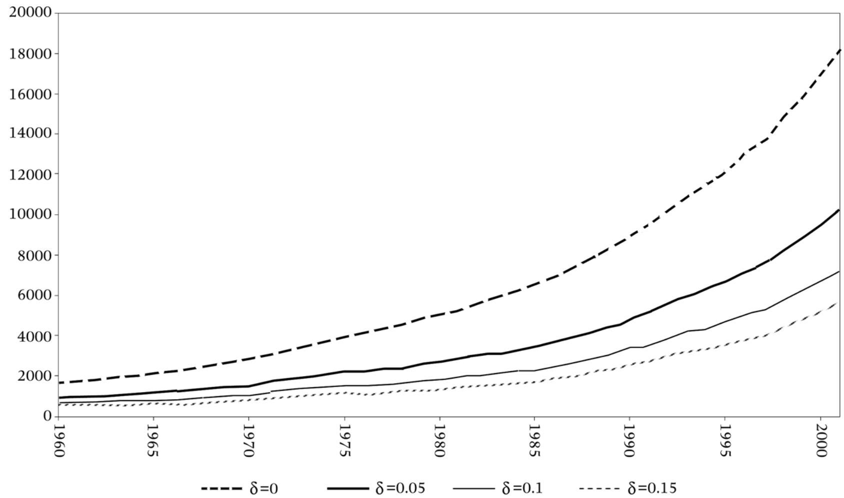
Such evidence seems to indicate that over the last four decades the Portuguese total and firm stock of knowledge have evolved favourably, which might to some extent constitute a potential factor of the Portuguese economic growth. In fact, Teixeira and Fortuna (2004), using the firm R&D capital stock estimated here, concluded that this latter constitutes an import growth factor of the Portuguese economy in the last forty years.

Analysing the average growth rates of the R&D capital stock (Table 2) it is possible to observe a slowdown in 1976–1980 and 1990–1995 periods and a recovering in the most recent period (1995–2001), particularly of the firm R&D capital stock.

3 A similar procedure was suggested by Coe and Helpman (1993) to foresee missing R&D data for a set of small countries.

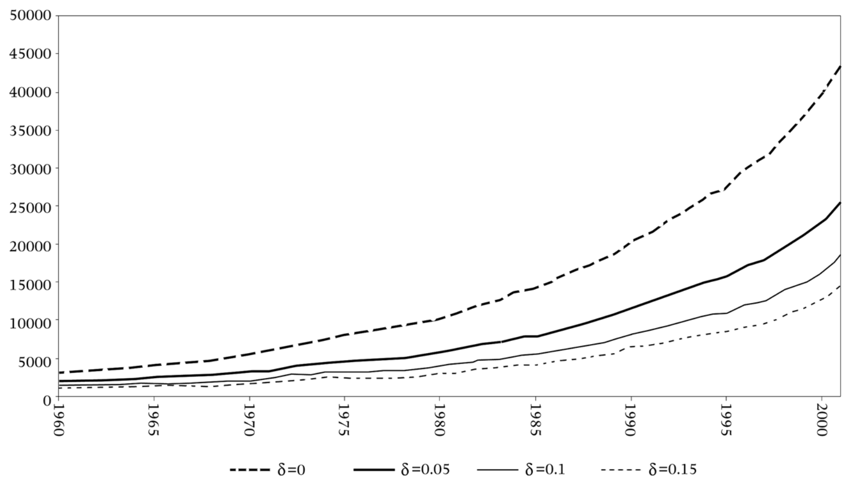
4 Caballero and Jaffe (1993) argue that knowledge obsolescence is an endogenous function of the number of new ideas. Here, for simplicity, we considered an exogenous depreciation rate.

5 One remarkable exception is the study by Nadiri and Prucha (1993) who estimated for the United States total manufacturing sector the depreciation rate of physical capital (5.9%) and R&D capital (12%).



Source: Author's own calculations (see Table A7 in the Appendix).

Figure 2: Total R&D capital stock assuming different rates of knowledge obsolescence (δ = 0%; δ = 5%; δ = 10%; δ = 15%), Portugal 1960–2001.



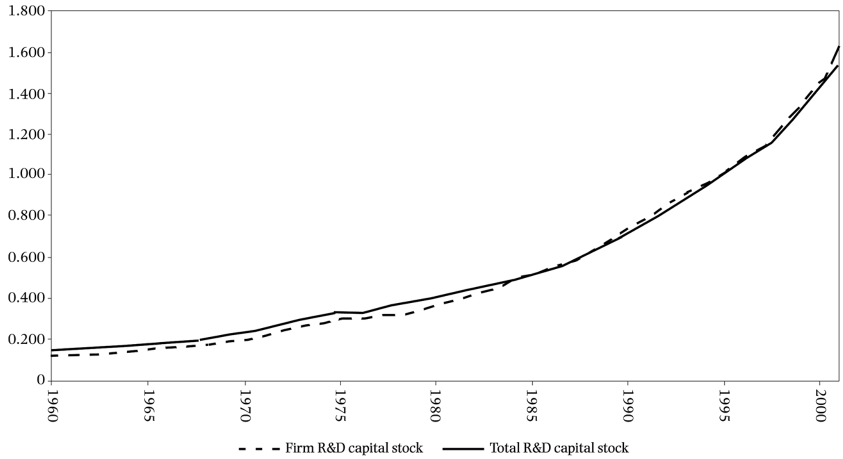
Source: Author's own calculations (see Table A8 in the Appendix).

Figure 3: Firm R&D capital stock assuming different rates of knowledge obsolescence (δ = 0%; δ = 5%; δ = 10%; δ = 15%), Portugal 1960–2001.

Conclusion

In a knowledge-based economy Research, Development (R&D) and Innovation are consider an essential element for the development of new products and processes, which in turn are critical to economic competitiveness, employment and the enhancement of an economy.

In fact, studies on endogenous economic growth (Grossman and Helpman 1991; Romer 1990; Aghion and Howitt 1998) consider commercially oriented innovation efforts that respond to economic incentives as a major



Source: Author's calculations (see Table A9 in the Appendix).

Figure 4: Total and Firm R&D capital stock, Portugal 1960–2001.

	Total R&D Capital Stock	Firm R&D Capital Stock
1964–1971	5.9	6.0
1971–1976	5.7	6.5
1976–1980	4.9	5.2
1980–1986	5.3	6.9
1986–1990	7.1	7.6
1990–1995	6.6	6.3
1995–2001	7.4	8.4

Sources: Author's calculations based on estimations in Table A9 in the Appendix.

Table 2: Average real growth rates (in per cent) of the Portuguese Total and Firm R&D Capital Stock.

engine of technological progress and productivity growth. It is argued that innovation feeds on knowledge that results from cumulative R&D experience on the one hand, and it contributes to this stock of knowledge on the other. Therefore, an economy's productivity level depends on its cumulative R&D effort and on its effective stock of knowledge, with the two being interrelated (Coe and Helpman 1993).

Progress in modelling knowledge at the empirical level has been falling behind progress at the theoretical level. Few generally accepted empirical measures of the stock of (technological) knowledge exist. Most of them are only available at cross-country level hampering long-term economic growth analysis of individual countries, given the absence of continuous time series.

In the present paper we provide a dynamic indicator of the Portuguese stock of technological knowledge or innovation capability since the 1960s up to 2001, based on R&D accumulated efforts. Following a perpetual inventory method, having total and firm R&D expenditures as benchmark indicators, we estimated total and firm R&D capital stock for the Portuguese economy.

Despite slowdowns observed in 1976–1980 and 1990–1995 periods, estimated data seem to indicate that over the last four decades the Portuguese total and firm stock of technological knowledge, that is, nation's innovation capability, have evolved satisfactorily. Most recently (1995–2001), particularly firm stock of technological knowledge has experience a notorious recovering, growing 8.4 per cent per year.

Appendix

Year	*Y*	*I*	P_Y	P_W
1960	295 614	62 438	0.298	0.114
1961	302 511	72 010	0.305	0.125
1962	336 688	75 739	0.304	0.132
1963	346 517	69 181	0.312	0.143
1964	361 599	81 112	0.315	0.155
1965	390 061	91 374	0.327	0.170
1966	411 073	104 403	0.345	0.185
1967	422 593	102 759	0.357	0.212
1968	470 979	117 840	0.362	0.228
1969	468 014	124 578	0.384	0.250
1970	514 242	127 339	0.397	0.285
1971	562 445	154 761	0.417	0.320
1972	603 356	185 375	0.450	0.366
1973	618 259	191 371	0.492	0.426
1974	603 066	192 072	0.585	0.561
1975	566 466	161 568	0.680	0.746
1976	607 875	157 794	0.791	0.882
1977	595 757	177 997	1.000	1.000
1978	630 206	180 207	1.217	1.135
1979	661 572	206 720	1.446	1.301
1980	681 982	204 154	1.745	1.601
1981	732 441	245 748	2.059	1.963
1982	728 669	247 866	2.487	2.360
1983	698 714	226 127	3.099	2.834
1984	702 200	198 866	3.862	3.101
1985	728 904	198 920	4.692	3.725
1986	755 184	203 461	5.652	4.473
1987	863 563	248 477	6.292	5.110
1988	892 900	279 132	7.018	5.910
1989	952 261	282 012	7.952	6.959
1990	993 633	292 810	9.106	8.214
1991	1 007 531	291 141	10.334	9.664
1992	1 101 349	320 684	10.815	11.023
1993	1 130 039	286 536	11.411	11.508
1994	1 131 214	280 019	12.183	11.913
1995	1 176 867	287 678	12.799	14.094
1996	1 314 033	302 862	13.186	15.432
1997	1 385 913	350 274	13.494	15.978
1998	1 466 451	391 076	13.861	15.582
1999	1 531 863	399 986	14.179	16.340
2000	1 580 325	419 351	14.591	17.136
2001	1 616 067	423 982	15.233	18.176

Notes: Y, *Gross Domestic Product, factor costs, 1977 constant prices, million escudos;* I, *Investment (FGCF), 1977 prices, million escudos;* P_Y, *GDP deflator (base year: 1977);* P_W, *Average earnings per worker index (base year: 1977).*
Data sources: Neves, João César das (1994), The Portuguese Economy: a picture in figures, Universidade Católica Editora; Banco de Portugal, Séries Longas da Economia Portuguesa; Banco de Portugal, Relatórios Anuais.

Table A1: Raw data used in the estimation of the Portuguese stock of technological knowledge.

Year	TR&D	FR&D	P_Y	$TR\&D_Y$	$FR\&D_Y$
1960	–	–	0.29792	–	–
1961	–	–	0.30472	–	–
1962	–	–	0.30414	–	–
1963	–	–	0.31161	–	–
1964	265.80	58.80	0.31510	843.50	186.60
1965	–	–	0.32713	–	–
1966	–	–	0.34510	–	–
1967	320.40	51.70	0.35691	897.70	144.90
1968	–	–	0.36190	–	–
1969	–	–	0.38397	–	–
1970	–	–	0.39705	–	–
1971	751.20	–	0.41716	1800.70	–
1972	854.20	214.30	0.44961	1899.90	476.60
1973	–	–	0.49206	–	–
1974	–	–	0.58502	–	–
1975	–	–	0.67978	–	–
1976	1279.60	269.60	0.79052	1618.70	341.00
1977	–	–	1.00000	–	–
1978	2521.10	331.70	1.21672	2072.00	272.60
1979	–	–	1.44626	–	–
1980	4118.50	1179.60	1.74495	2360.20	676.00
1981	–	–	2.05945	–	–
1982	6541.20	2043.60	2.48686	2630.30	821.80
1983	–	–	3.09950	–	–
1984	11 307.60	3347.70	3.86185	2928.00	866.90
1985	–	–	4.69220	–	–
1986	19 867.60	5215.70	5.65181	3515.30	922.80
1987	–	–	6.29232	–	–
1988	29 910.80	7351.00	7.01767	4262.20	1047.50
1989	–	–	7.95206	–	–
1990	52 032.20	13 585.60	9.10568	5714.30	1492.00
1991	–	–	10.33365	–	–
1992	80 397.80	17 452.20	10.81482	7434.00	1613.70
1993	–	–	11.41124	–	–
1994	–	–	12.18295	–	–
1995	92 229.20	19 291.90	12.79895	7206.00	1507.30
1996	–	–	13.18612	–	–
1997	115 654.60	25 975.60	13.49435	8570.60	1924.90
1998	–	–	13.86067	–	–
1999	163 342.10	37 048.50	14.17947	11 519.60	2612.80
2000	–	–	14.59067	–	–
2001	203 131.70	65 920.00	15.23266	13 335.30	4327.50

Notes: TR&D, Total Research and Development expenditure, current prices (million escudos); FR&D, Firm Research and Development expenditures, current prices (million escudos); P_Y*, GDP deflator (base year: 1977); TR&DY, Total Research and Development expenditure, constant prices (million escudos); FR&DY, Firm Research and Development expenditures, constant prices (million escudos).*

Data sources: 1964–72: JNICT (1986), Indicadores de Ciência e Tecnologia Portugal 1964–1982; 1976–90: INE, Anuário Estatístico do INE; 1991–2001: INE, Anuário Estatístico do INE; PY: Neves, J.C. (1994), The Portuguese Economy: picture in figures, Universidade Católica Editora.

Table A2: Real R&D (total and firm) expenditures, using GDP deflator.

Anos	Current expenditures	Labour expenditures	Other current expenditures	Capital expenditures
1964	87.25	57.45	29.80	12.75
1967	85.40	57.15	28.25	14.61
1972	86.52	60.96	25.56	13.49
1976	89.59	69.90	19.69	10.41
1980	76.75	57.13	19.62	23.26
1982	82.11	62.72	19.39	17.90
1986	75.04	54.07	20.97	24.96
1988	78.64	59.10	19.54	21.37
1990	79.85	60.29	19.56	20.15
1992	73.55	57.24	16.31	16.45
1999	83.53	62.60	20.93	16.47
2001	81.28	61.73	19.55	18.72
Average		60.03		

Data sources: 1964–72: JNICT (1986), Indicadores de Ciência e Tecnologia Portugal 1964–1982; 1976–90: INE, Anuário Estatistico do INE; 1991–2001: INE, Anuário Estatistico do INE.

Table A3: Decomposition of R&D expenditures – share of labour costs.

Year	P_Y	P_W	$P_{R\&D}$
1960	0.29792	0.11433	0.18771
1961	0.30472	0.12455	0.19656
1962	0.30414	0.13177	0.20067
1963	0.31161	0.14296	0.21037
1964	0.31510	0.15453	0.21871
1965	0.32713	0.16974	0.23265
1966	0.34510	0.18466	0.24879
1967	0.35691	0.21161	0.26969
1968	0.36190	0.22833	0.28172
1969	0.38397	0.24991	0.30349
1970	0.39705	0.28477	0.32965
1971	0.41716	0.31961	0.35860
1972	0.44961	0.36567	0.39922
1973	0.49206	0.42551	0.45211
1974	0.58502	0.56085	0.57051
1975	0.67978	0.74566	0.71933
1976	0.79052	0.88196	0.84541
1977	1.00000	1.00000	1.00000
1978	1.21672	1.13454	1.16739
1979	1.44626	1.30051	1.35876
1980	1.74495	1.60124	1.65868
1981	2.05945	1.96276	2.00140
1982	2.48686	2.36016	2.41080
1983	3.09950	2.83414	2.94020
1984	3.86185	3.10099	3.40510
1985	4.69220	3.72516	4.11169
1986	5.65181	4.47293	4.94413
1987	6.29232	5.11028	5.58274
1988	7.01767	5.91011	6.35280
1989	7.95206	6.95933	7.35612
1990	9.10568	8.21412	8.57048
1991	10.33365	9.66372	9.93149
1992	10.81482	11.02263	10.93957
1993	11.41124	11.50817	11.46943
1994	12.18295	11.91343	12.02116
1995	12.79895	14.09407	13.57641
1996	13.18612	15.43175	14.53417
1997	13.49435	15.97825	14.98543
1998	13.86067	15.58160	14.89375
1999	14.17947	16.34012	15.47651
2000	14.59067	17.13581	16.11852
2001	15.23266	18.17554	16.99927

Notes: P_Y, *GDP deflator (base year: 1977);* P_W, *Average earnings per worker index (base year: 1977);* $P_{R\&D}$; *R&D deflator [*$P_{R\&D} = 0.3997 * P_Y + 0.6003 * P_W$*]. The construction of* $P_{R\&D}$ *was based on Coe and Helpman's (1993) study. However, differently from Coe and Helpman we considered the efective composition of R&D expenditures (from Table A3 we concluded that, on average, labour costs represented 60.03% of total costs).*
Data sources: Idem Table A1.

Table A4: GDP, Wages and R&D deflators.

Year	TR&D	FR&D	$P_{R\&D}$	TR&D($P_{R\&D}$)	FR&D($P_{R\&D}$)
1960	–	–	0.1877	–	–
1961	–	–	0.1966	–	–
1962	–	–	0.2007	–	–
1963	–	–	0.2104	–	–
1964	265.80	58.80	0.2187	1215.30	268.80
1965	–	–	0.2327	–	–
1966	–	–	0.2488	–	–
1967	320.40	51.70	0.2697	1188.00	191.70
1968	–	–	0.2817	–	–
1969	–	–	0.3035	–	–
1970	–	–	0.3296	–	–
1971	751.20	–	0.3586	2094.80	–
1972	854.20	214.30	0.3992	2139.70	536.80
1973	–	–	0.4521	–	–
1974	–	–	0.5705	–	–
1975	–	–	0.7193	–	–
1976	1279.60	269.60	0.8454	1513.60	318.90
1977	–	–	1.0000	–	–
1978	2521.10	331.70	1.1674	2159.60	284.10
1979	–	–	1.3588	–	–
1980	4118.50	1179.60	1.6587	2483.00	711.20
1981	–	–	2.0014	–	–
1982	6541.20	2043.60	2.4108	2713.30	847.70
1983	–	–	2.9402	–	–
1984	11 307.60	3347.70	3.4051	3320.80	983.10
1985	–	–	4.1117	–	–
1986	19 867.60	5215.70	4.9441	4018.40	1054.90
1987	–	–	5.5827	–	–
1988	29 910.80	7351.00	6.3528	4708.30	1157.10
1989	–	–	7.3561	–	–
1990	52 032.20	13 585.60	8.5705	6071.10	1585.20
1991	–	–	9.9315	–	–
1992	80 397.80	17 452.20	10.9396	7349.30	1595.30
1993	–	–	11.4694	–	–
1994	–	–	12.0212	–	–
1995	92 229.20	19 291.90	13.5764	6793.30	1421.00
1996	–	–	14.5342	–	–
1997	115 654.60	25 975.60	14.9854	7717.80	1733.40
1998	–	–	14.8937	–	–
1999	163 342.10	37 048.50	15.4765	10 554.20	2393.90
2000	–	–	16.1185	–	–
2001	203 131.70	65 920.00	16.9993	11 949.40	3877.80

Notes: TR&D, Total Research and Development expenditure, current prices (million escudos); FR&D, Firm Reseach and Development expenditures, current prices (million escudos); IDT($P_{R\&D}$*), Total Research and Development expenditure, constant 1977 prices (million escudos); IDE(*$P_{R\&D}$*), Firm Reseach and Development expenditures, coinstant 1977 prices (million escudos).*
Data sources: Idem Tables A1 and A4.1.

Table A5: Total and firm real R&D expenditures using R&D deflator.

Year	y	tr&d est	rtr&d est	rtr&d est/ef	fr&d est	rfr&d est	rfr&d est/ef
1960	12.5968	6.5309	686.00	686.00	4.9001	134.30	134.30
1961	12.6199	6.5694	712.90	712.90	4.9427	140.10	140.10
1962	12.7269	6.7480	852.40	852.40	5.1401	170.70	170.70
1963	12.7557	6.7961	894.30	894.30	5.1931	180.00	180.00
1964	12.7983	6.8672	960.20	1215.30	5.2717	194.70	268.80
1965	12.8741	6.9936	1089.60	1089.60	5.4114	224.00	224.00
1966	12.9265	7.0812	1189.40	1189.40	5.5082	246.70	246.70
1967	12.9542	7.1273	1245.50	1188.00	5.5592	259.60	191.70
1968	13.0626	7.3082	1492.50	1492.50	5.7591	317.10	317.10
1969	13.0563	7.2977	1476.80	1476.80	5.7474	313.40	313.40
1970	13.1504	7.4549	1728.20	1728.20	5.9212	372.80	372.80
1971	13.2400	7.6044	2007.00	2094.80	6.0864	439.80	439.80
1972	13.3103	7.7216	2256.50	2139.70	6.2159	500.60	536.80
1973	13.3347	7.7623	2350.30	2350.30	6.2609	523.70	523.70
1974	13.3098	7.7208	2254.70	2254.70	6.2150	500.20	500.20
1975	13.2472	7.6163	2031.00	2031.00	6.0995	445.70	445.70
1976	13.3177	7.7340	2284.80	1513.60	6.2297	507.60	318.90
1977	13.2976	7.7004	2209.30	2209.30	6.1925	489.10	489.10
1978	13.3538	7.7942	2426.60	2159.60	6.2962	542.50	284.10
1979	13.4024	7.8753	2631.40	2631.40	6.3858	593.30	593.30
1980	13.4328	7.9260	2768.30	2483.00	6.4418	627.50	711.20
1981	13.5041	8.0451	3118.50	3118.50	6.5735	715.80	715.80
1982	13.4990	8.0365	3091.80	2713.30	6.5639	709.10	847.70
1983	13.4570	7.9664	2882.60	2882.60	6.4865	656.20	656.20
1984	13.4620	7.9747	2906.60	3320.80	6.4957	662.30	983.10
1985	13.4993	8.0370	3093.40	3093.40	6.5645	709.50	709.50
1986	13.5347	8.0961	3281.80	4018.40	6.6298	757.40	1054.90
1987	13.6688	8.3199	4104.90	4104.90	6.8772	969.90	969.90
1988	13.7022	8.3757	4340.30	4708.30	6.9388	1031.50	1157.10
1989	13.7666	8.4831	4832.50	4832.50	7.0575	1161.50	1161.50
1990	13.8091	8.5541	5187.90	6071.10	7.1359	1256.30	1585.20
1991	13.8230	8.5773	5309.60	5309.60	7.1615	1288.90	1288.90
1992	13.9120	8.7258	6160.10	7349.30	7.3257	1518.90	1595.30
1993	13.9378	8.7688	6430.20	6430.20	7.3732	1592.60	1592.60
1994	13.9388	8.7705	6441.40	6441.40	7.3751	1595.70	1595.70
1995	13.9784	8.8365	6881.10	6793.30	7.4480	1716.50	1421.00
1996	14.0886	9.0205	8271.00	8271.00	7.6514	2103.50	2103.50
1997	14.1419	9.1094	9039.80	7717.80	7.7496	2320.60	1733.40
1998	14.1984	9.2037	9933.40	9933.40	7.8537	2575.40	2575.40
1999	14.2420	9.2765	10 683.80	10 554.20	7.9342	2791.20	2393.90
2000	14.2731	9.3285	11 253.80	11 253.80	7.9917	2956.20	2956.20
2001	14.2955	9.3658	11 681.80	11 949.40	8.0329	3080.70	3877.80

Notes: Small letters indicates the natural logarithm of the variables (TR&D, FR&D and GDP). In order to obtain the missing values for real expenditures in R&D, we follow Coe and Helpman's (1993) suggestion estimating an equation relating real R&D expenditures with real GDP and investment (all in logs). However, given that investment was not statistically significant, we opt to estimate R&D expenditures using only real GDP as independent variable.

rtr&d est (trdt) was estimated by OLS as follows:

$$\text{trd}_t = -14.570 + 1.674 y_t + \hat{e}_t;\ \overline{R}^2 = 0.95$$
$$(-10.397)\ (16.269)$$

rfr&d est (frdt) was estimated by OLS as follows:

$$\text{frd}_t = -18.331 + 1.844 y_t + \hat{e}_t;\ \overline{R}^2 = 0.872$$
$$(-7.121)\ (9.754)$$

Table A6: Estimating by OLS missing values of total and firm R&D stock.

Year	RTR&D	RTR&D est	$\delta = 0$	$\delta = 0.05$	$\delta = 0.1$	$\delta = 0.15$
1960	–	686.00	16 612.00	9726.20	7111.10	5784.50
1961	–	712.90	17 324.90	9952.80	7112.90	5629.80
1962	–	852.40	18 177.30	10 307.60	7254.00	5637.70
1963	–	894.30	19 071.60	10 686.50	7422.90	5686.40
1964	1215.30	1215.30	20 286.90	11 367.50	7895.90	6048.70
1965	–	1089.60	21 376.60	11 888.80	8196.00	6231.00
1966	–	1189.40	22 565.90	12 483.70	8565.80	6485.70
1967	1188.00	1188.00	23 754.00	13 047.60	8897.20	6700.90
1968	–	1492.50	25 246.50	13 887.70	9500.00	7188.30
1969	–	1476.80	26 723.30	14 670.10	10 026.80	7586.90
1970	–	1728.20	28 451.50	15 664.90	10 752.40	8177.10
1971	2094.80	2094.80	30 546.40	16 976.40	11 772.00	9045.30
1972	2139.70	2139.70	32 686.00	18 267.30	12 734.40	9828.20
1973	–	2350.30	35 036.30	19 704.20	13 811.30	10 704.20
1974	–	2254.70	37 291.00	20 973.60	14 684.80	11 353.30
1975	–	2031.00	39 321.90	21 955.90	15 247.30	11 681.30
1976	1513.60	1513.60	40 835.50	22 371.70	15 236.20	11 442.70
1977	–	2209.30	43 044.80	23 462.40	15 921.80	11 935.50
1978	2159.60	2159.60	45 204.40	24 448.90	16 489.20	12 304.80
1979	–	2631.40	47 835.80	25 857.90	17 471.80	13 090.50
1980	2483.00	2483.00	50 318.80	27 048.00	18 207.60	13 609.90
1981	–	3118.50	53 437.40	28 814.10	19 505.30	14 687.00
1982	2713.30	2713.30	56 150.70	30 086.70	20 268.10	15 197.20
1983	–	2882.60	59 033.20	31 464.90	21 123.90	15 800.20
1984	3320.80	3320.80	62 354.00	33 212.50	22 332.30	16 751.00
1985	–	3093.40	65 447.40	34 645.30	23 192.50	17 331.70
1986	4018.40	4018.40	69 465.90	36 931.40	24 891.60	18 750.40
1987	–	4104.90	73 570.80	39 189.80	26 507.40	20 042.80
1988	4708.30	4708.30	78 279.10	41 938.60	28 565.00	21 744.60
1989	–	4832.50	83 111.50	44 674.10	30 540.90	23 315.40
1990	6071.10	6071.10	89 182.60	48 511.50	33 557.90	25 889.20
1991	–	5309.60	94 492.20	51 395.50	35 511.70	27 315.40
1992	7349.30	7349.30	101 841.50	56 175.00	39 309.80	30 567.40
1993	–	6430.20	108 271.70	59 796.50	41 809.10	32 412.50
1994	–	6441.40	114 713.10	63 248.10	44 069.50	33 992.00
1995	6793.30	6793.30	121 506.40	66 879.00	46 455.90	35 686.50
1996	–	8271.00	129 777.40	71 806.00	50 081.30	38 604.50
1997	7717.80	7717.80	137 495.20	75 933.50	52 791.00	40 531.70
1998	–	9933.40	147 428.60	82 070.20	57 445.30	44 385.30
1999	10 554.20	10 554.20	157 982.80	88 520.90	62 254.90	48 281.70
2000	–	11 253.80	169 236.60	95 348.60	67 283.20	52 293.20
2001	11 949.40	11 949.40	181 186.00	102 530.60	72 504.30	56 398.70

Notes:

Real average annual growth rate of total R&D expenditures: $g = \left[\left(\frac{\text{RTR \& D2001}}{\text{RTR \& D1964}}\right)^{1/37} - 1\right] = 0.06372.$

Estimated initial stock of total R&D expenditures: $\frac{\text{RTR \& D1964}}{g + \delta}.$

$\delta = 0 \Rightarrow \text{SR \& D}_0 = 19071.6$; $\delta = 0.50 \Rightarrow \text{SR \& D}_0 = 10686.5$; $\delta = 0.1 \Rightarrow \text{SR \& D}_0 = 7422.9$; $\delta = 0.15 \Rightarrow \text{SR \& D}_0 = 5686.4$.

Table A7: Estimation of the stock of technological knowledge based on total R&D expenditures for several knowledge obsolescence rates.

Year	RFR&D	RFR&D est	$\delta = 0$	$\delta = 0.05$	$\delta = 0.1$	$\delta = 0.15$
1960	–	134.30	3103.50	1966.00	1496.40	1253.10
1961	–	140.10	3243.60	2007.80	1486.90	1205.30
1962	–	170.70	3414.30	2078.20	1508.90	1195.20
1963	–	180.00	3594.40	2154.30	1538.10	1196.00
1964	268.80	268.80	3863.20	2315.40	1653.10	1285.40
1965	–	224.00	4087.20	2423.60	1711.70	1316.60
1966	–	246.70	4333.90	2549.10	1787.30	1365.80
1967	191.70	191.70	4525.60	2613.40	1800.30	1352.60
1968	–	317.10	4842.70	2799.80	1937.30	1466.80
1969	–	313.40	5156.00	2973.20	2057.00	1560.20
1970	–	372.80	5528.90	3197.40	2224.10	1699.00
1971	–	439.80	5968.70	3477.30	2441.50	1884.00
1972	536.80	536.80	6505.50	3840.30	2734.20	2138.20
1973	–	523.70	7029.20	4171.90	2984.40	2341.10
1974	–	500.20	7529.40	4463.50	3186.20	2490.20
1975	–	445.70	7975.10	4686.00	3313.20	2562.30
1976	318.90	318.90	8294.00	4770.60	3300.80	2496.80
1977	–	489.10	8783.00	5021.20	3459.80	2611.40
1978	284.10	284.10	9067.20	5054.20	3398.00	2503.80
1979	–	593.30	9660.50	5394.90	3651.50	2721.60
1980	711.20	711.20	10 371.70	5836.30	3997.50	3024.50
1981	–	715.80	11 087.50	6260.30	4313.60	3286.70
1982	847.70	847.70	11 935.20	6795.00	4729.90	3641.40
1983	–	656.20	12 591.40	7111.50	4913.20	3751.40
1984	983.10	983.10	13 574.60	7739.00	5405.00	4171.80
1985	–	709.50	14 284.10	8061.60	5574.00	4255.50
1986	1054.90	1054.90	15 339.00	8713.40	6071.50	4672.10
1987	–	969.90	16 308.90	9247.60	6434.20	4941.20
1988	1157.10	1157.10	17 466.00	9942.40	6947.90	5357.10
1989	–	1161.50	18 627.50	10 606.80	7414.70	5715.10
1990	1585.20	1585.20	20 212.70	11 661.60	8258.30	6443.00
1991	–	1288.90	21 501.60	12 367.40	8721.40	6765.40
1992	1595.30	1595.30	23 096.90	13 344.30	9444.60	7345.90
1993	–	1592.60	24 689.50	14 269.80	10 092.80	7836.70
1994	–	1595.70	26 285.20	15 152.00	10 679.20	8256.90
1995	1421.00	1421.00	27 706.20	15 815.40	11 032.30	8439.30
1996	–	2103.50	29 809.70	17 128.10	12 032.50	9276.90
1997	1733.40	1733.40	31 543.10	18 005.10	12 562.70	9618.80
1998	–	2575.40	34 118.50	19 680.20	13 881.80	10 751.30
1999	2393.90	2393.90	36 512.30	21 090.00	14 887.40	11 532.50
2000	–	2956.20	39 468.50	22 991.80	16 354.90	12 758.80
2001	3877.80	3877.80	43 346.40	25 720.00	18 597.20	14 722.80

Notes:

Real average annual growth rate of total R&D expenditures: $g = \left[\left(\frac{\text{RFR \& D2001}}{\text{RFR \& D1964}}\right)^{1/37} - 1\right] = 0.0748.$

Estimated initial stock of total R&D expenditures: $\frac{\text{RFR \& D1964}}{g + \delta}$.

$\delta = 0 \Rightarrow \text{SR \& D}_0 = 3594.4$; $\delta = 0.05 \Rightarrow \text{SR \& D}_0 = 2154.3$; $\delta = 0.1 \Rightarrow \text{SR \& D}_0 = 1538.1$; $\delta = 0.15 \Rightarrow \text{SR \& D}_0 = 1196.0$.

Table A8: Estimation of the stock of technological knowledge based on firm R&D expenditures for several knowledge obsolescence rates.

Year	TR&DS	FR&DS	KS_T	KS_{FIRM}
1960	9726.20	1966.00	0.1454	0.1243
1961	9952.80	2007.80	0.1488	0.1270
1962	10 307.60	2078.20	0.1541	0.1314
1963	10 686.50	2154.30	0.1598	0.1362
1964	11 367.50	2315.40	0.1700	0.1464
1965	11 888.80	2423.60	0.1778	0.1532
1966	12 483.70	2549.10	0.1867	0.1612
1967	13 047.60	2613.40	0.1951	0.1652
1968	13 887.70	2799.80	0.2077	0.1770
1969	14 670.10	2973.20	0.2194	0.1880
1970	15 664.90	3197.40	0.2342	0.2022
1971	16 976.40	3477.30	0.2538	0.2199
1972	18 267.30	3840.30	0.2731	0.2428
1973	19 704.20	4171.90	0.2946	0.2638
1974	20 973.60	4463.50	0.3136	0.2822
1975	21 955.90	4686.00	0.3283	0.2963
1976	22 371.70	4770.60	0.3345	0.3016
1977	23 462.40	5021.20	0.3508	0.3175
1978	24 448.90	5054.20	0.3656	0.3196
1979	25 857.90	5394.90	0.3866	0.3411
1980	27 048.00	5836.30	0.4044	0.3690
1981	28 814.10	6260.30	0.4308	0.3958
1982	30 086.70	6795.00	0.4499	0.4296
1983	31 464.90	7111.50	0.4705	0.4497
1984	33 212.50	7739.00	0.4966	0.4893
1985	34 645.30	8061.60	0.5180	0.5097
1986	36 931.40	8713.40	0.5522	0.5509
1987	39 189.80	9247.60	0.5860	0.5847
1988	41 938.60	9942.40	0.6271	0.6287
1989	44 674.10	10 606.80	0.6680	0.6707
1990	48 511.50	11 661.60	0.7254	0.7374
1991	51 395.50	12 367.40	0.7685	0.7820
1992	56 175.00	13 344.30	0.8400	0.8438
1993	59 796.50	14 269.80	0.8941	0.9023
1994	63 248.10	15 152.00	0.9457	0.9581
1995	66 879.00	15 815.40	1.0000	1.0000
1996	71 806.00	17 128.10	1.0737	1.0830
1997	75 933.50	18 005.10	1.1354	1.1385
1998	82 070.20	19 680.20	1.2271	1.2444
1999	88 520.90	21 090.00	1.3236	1.3335
2000	95 348.60	22 991.80	1.4257	1.4538
2001	102 530.60	25 720.00	1.5331	1.6263

Notes: KS_T, Index of Total Stock of Knowledge (1995 = 1); KS_{FIRM}, Index of Firm Stock of Knowledge (1995 = 1).

Table A9: Portuguese Stock of Technological Knowledge, 1960–2001 (Index 1995 = 1).

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