CENTRE OF PLANNING AND ECONOMIC RESEARCH

No 32

Measurement Errors and the Indirect Effects of R & D on Productivity Growth: The U.S. Manufacturing Sector

by

Z. GEORGANTA

November 1993

Zoe Georganta
Centre of Planning
and Economic Research
and University of Macedonia

Measurement Errors and the Indirect Effects of R & D on Productivity Growth: The U.S. Manufacturing Sector

Opinions or value judgements expressed in this book
are those of the author and do not necessarily
represent those of the Centre of Planning
and Economic Research.

CENTRE OF PLANNING AND ECONOMIC RESEARCH

The Centre of Planning and Economic Research (KEPE) was established as a research unit, under the title "Centre of Economic Research", in 1959. Its primary aims were the scientific study of the problems of the Greek economy, encouragement of economic research and cooperation with other scientific institutions.

In 1964, the Centre acquired its present name and organizational structure, with the following additional objectives: (a) The preparation of short, medium and long-term development plans, including plans for regional and territorial development and also public investment plans, in accordance with guidelines laid down by the Government. (b) The analysis of current developments in the Greek economy along with appropriate short-term and medium-term forecasts; also, the formulation of proposals for appropriate stabilization and development measures. (c) The further education of young economists, particularly in the fields of planning and economic development.

The Centre has been and is very active in all of the above fields, and carries out systematic basic research in the problems of the Greek economy, formulates draft development plans, analyses and forecasts short-term and medium-term developments, grants scholarships for post-graduate studies in economics and planning and organizes lectures and seminars.

Within the framework of these activities, the Centre also publishes studies from research carried out at the Centre, reports which are usually the result of collective work by groups of experts which are set up for the preparation of development programmes, and lectures given by specially invited distinguished scientists.

The Centre is in continuous contact with similar scientific institutions abroad and exchanges publications, views and information on current economic topics and methods of economic research, thus further contributing to the advancement of the science of economics in the country.

DISCUSSION PAPER SERIES

This series of Discussion Papers is designed to speed up the dissemination of research work prepared by the staff of KEPE and by its external collaborators with a view to subsequent publication. Timely comment and criticism for its improvement is appreciated.

ACKNOWLEDGEMENTS

I wish to thank Dr. K.A. Mork of the SNF Center for Research in Economics, Norway, as well as participants in the Econometric Society European Meeting, EC62 Factor Productivity Models, held in Brussels, August 1992, for useful comments on an earlier version of this paper.

CONTENTS

LIST OF TABLES

ABSTRACT

This paper explores the indirect relationship between productivity growth and R&D intensity. First, it develops a LISREL model with errors of measurement in productivity figures and output deflators. The model uses a cross-section of 279 U.S. manufacturing industries for the year 1982 as compared to 1977. R&D expenditures are distinguished between process-oriented and product-oriented components, which are influencing productivity growth indirectly through their direct effect on product quality-change. The model estimates show a significant 5.4 percent rate of return to "imported" from other industries R&D. This result strengthens a previous finding for 1977/1972, giving support to an "errors of measurement" explanation of the "productivity puzzle".

I. INTRODUCTION

For a long time, it has been widely accepted that technical innovations in new or improved products, as well as in new or improved production processes, are an important source of productivity growth. Consequently, the relationship between technological advance and productivity change has extensively been investigated in past and recent literature. Mairesse and Sassenou [1991] have surveyed the econometric work done in this field at the firm level. There are also numerous studies investigating the relationship between technology and productivity at the four-digit SIC industry level, as well as a more aggregated level.[1] This paper offers more empirical evidence on this long-debated issue within the framework of an errors-of-measurement model by using a better data set.[2]

Within the econometric approach of analysis, economists have traditionally used research and development (R&D) spending to account for technological progress. The choice is due to conceptual clarity of activities included in R&D expenditures, as well as their satisfactory statistical coverage. On the other hand, productivity is most frequently defined in terms of total factor productivity (TFP) growth. TFP growth is defined as the growth of output after subtracting the growth attributable to increases in inputs weighted by their share in total output.

The impetus to the intensive study of the relationship between R&D and productivity growth was given by the observation that during the last twenty years or so productivity growth has not kept up with the perceived technological developments. This phenomenon is known in the literature as a "productivity paradox" or "puzzle", and a lot of reasons have been offered as its explanations.[3]

This paper can be considered as investigating the "productivity paradox" within the framework of a LISREL (LInear Structural RELations) model[4] which takes explicit account of errors of measurement in TFP growth, as well as in output deflators used to obtain the TFP growth figures.[5] Measurement errors may be caused by a variety of reasons, but product-

---

[1]. Specifically, see Griliches [1980], and Griliches and Lichtenberg [1984a,b].

[2]. See U.S. Department of Labor, Bureau of Labor Statistics [1986].

[3]. See "Technology and Productivity", OECD, 1991, and the "Symposium on the Slowdown in Productivity Growth", Journal of Economic Perspectives, Vol. 2, No. 4, 1988.

[4]. See Hayduk [1987], Joreskog and Sorbom [1989], and Bollen [1989].

[5]. Measurement issues were one of the main themes in the classic debate between Denison on the one hand and Jorgenson and Griliches on the other. (See Survey of Current Business, May 1969, Vol.49, No.5,Part II.) Since then, measurement-error considerations have lead to Griliches and Lichtenberg [1984b] and Lichtenberg and Griliches [1989], while

quality change is the most prevalent in the literature.[1] Specifically, it is more than thirty years that economists have discussed about the failure of official price indexes to adjust to quality change, have warned about the consequences of such a deficiency, and have urged authorities in the statistical agencies to implement the "hedonic" approach in order to properly face the quality issue.[2] If product-quality change is not properly treated, we may end in pseudo-inflationary prices, which may not properly reflect the corresponding social returns from the new or improved items appearing in the market. Consequently, the growth in real output and productivity figures may appear slower or faster than it actually is. For instance, the annual rate of growth of real equipment investment in the U.S. official data during 1947-83 was 3.2%, while if Gordon's [1990] quality-adjusted deflator is used, this annual growth rate becomes 6.1%.

This paper quantifies the indirect effects of four different R&D intensities on TFP growth taking into account the presence of errors of measurement due to unaccounted product-quality change. The empirical application refers to the manufacturing sector of the U.S. economy, at the four-digit SIC industry level, for the period 1977-1982.

Among the main findings of this work is that three out of the four studied R&D intensities have strong positive indirect effects on TFP growth through their direct effects on product-quality change. These three R&D variables refer to product-oriented R&D spending. The fourth variable, which exhibits a significant but less strong effect on total factor productivity growth, refers to process-oriented R&D spending. In general, most of the estimated rates of return to R&D are strongly significant and for the first time well above unity.

The paper is organized as follows: Section II discusses the specification of the LISREL model. Section III gives an overview of the data, and Section IV presents and discusses the maximum likelihood estimates of the model. The last Section concludes the paper.

Griliches [1973, 1979, 1988, 1991] has been for long discussing that measurement errors may have serious consequences on economic growth figures. Baily and Gordon [1988], as well as Gordon [1990, pp. 8-14] have also stressed the importance of measurement issues.

[1]. See Griliches [1990] and Triplett [1990]. Also, Gordon [1990] and Triplett [1983, 1988].

[2]. See Price Statistics Review Committee [1961], Griliches [1971], Gordon [1990].

II. DEVELOPMENT OF THE LISREL MODEL

It is well known that quality change is difficult to define within the framework of the economics discipline and even more difficult to measure. This is apparent from the numerous studies and disagreements among famous economists of the field.[1] Gordon [1971, p. 131] says that "The problem of adjusting price indexes for quality change consists of decomposing changes in the value (V) of a group of units into changes in price (P), changes in quality (Q), and changes in the number of units (X):

$dV/V = dP/P + dQ/Q + dX/X$".

In this paper quality change is defined as follows: Observed price change includes a "pure" price-change component and it also depends on a quality-change component. If P denotes observed price-change, P^* denotes "pure" price-change, and Z^* denotes quality-change, then

$$P = P^* + \lambda Z^* \qquad (1)$$

where λ is any real number and represents a quality-adjustment coefficient. If $\lambda = 0$, then observed prices are fully quality-adjusted, thus reflecting only "pure" price-change. If $\lambda = 1$, then equation (1) becomes

$$P = P^* + Z^* \qquad (2)$$

and observed prices are not quality-adjusted, thus reflecting a "pure" price-change component plus a "pure" quality-change component.

Summarizing the above, if $0 \leq \lambda \leq 1$, then observed prices adjust to quality-change by $1-\lambda$. If $\lambda > 1$, then observed prices not only are they non-quality-adjusted, but they also reflect a third component equal to $(\lambda-1)Z^*$. Thus, $P = P^* + Z^* + (\lambda-1)Z^*$. In this case observed prices are more distorted. On the other hand, if $\lambda < 0$, then observed prices are downward biased.[2] The literature supports both upward and downward bias in price change. Griliches and Triplett have been the two main opponents in this debate. Griliches indicated the

---

[1]. See, among others, Denison [1957, 1971], Larsgaard and Mack [1961], Jorgenson and Griliches [1967], Triplett [1970, 1971], Gordon [1971, 1990], Griliches [1971].

[2]. An example of such a case may be include the expressed criticism about the application of the hedonic approach to computer price indexes as having lead to unreasonably low prices. See Triplett [1990, pp. 226-228].

likelihood of a major upward bias in official measures of price change, while Triplett supported the possibility of bias in both directions.[1]

Equation (1) can be written as $Z^{*}=P-P^{*}$, $\lambda=1$. Thus, quality change may be defined as the difference between observed price change and "pure" or "true" price change. This definition is equivalent to Lichtenberg and Griliches [1989, p. 6], who define "the growth rate of product quality, Z^{*}, as the difference between the growth rate of the effective quantity of output Q^{*} and the growth rate of number of units sold, Q: $Z^{*}=Q^{*}-Q$. Defining the growth in the price of effective output as $P^{*}\equiv VQ-Q^{*}$ (where VQ denotes the growth in nominal output) and defining the growth in the price per unit sold as $P\equiv VQ-Q$ yields the identity $P=P^{*}+Z^{*}$.". The definition of this paper and that of Lichtenberg and Griliches [1989, p. 6] differ in the range definition of λ. Their λ can only move between 0 and 1. Thus, Lichtenberg and Griliches [1989] treat failure to adjust for quality change as one single case: lack of quality adjustment. Consequently, it does not fully describe the extent to which a given price index distorts true price change, P^{*}.

Gordon's [1990, p. 18] quality-change adjustment considers "the percentage difference for the new and old models in the selling price and the ability to generate net revenue at a fixed set of output and variable input prices. If the introduction of a new model raises the selling price and ability to generate net revenue in exact proportion, then this "proportional" quality change implies no change in the "real" price caused by the new model introduction, and the nominal price change for this product can be measured by the behavior of nominal prices for models that remain unchanged in the two adjacent time periods affected by the new-model introduction. If, however, the introduction of a new model raises the selling price by less than the ability to generate net revenue,...,a "real" price decline is recorded, and this negative change in the real price is added to the recorded nominal price change for models that remain identical in the time period affected by the introduction of the new model.". Gordon also adjusts prices for changes in energy use and in the frequency of repair, but he considers only durable goods.

Quality-change, Z^{*}, in this paper is specified as a stochastic conceptuous or unobserved variable. This specification is more realistic, since it permits, through the error terms, the statistical evaluation of the influence of a big variety of factors on product quality-change. This is important if we consider Gordon [1990, pp. 38-39 and 154], who refers to 23 reasons why his quality-adjusted indexes may actually be too "conservative".

Within the above framework the LISREL model, which is developed in this Section, consists of two sub-models: a measurement one and a structural one. They are specified as follows:

---

[1]. Gordon [1990] reports evidence that the bias in the limited case of durable components of both CPI (Consumer Price Index) and the PPI (Producer Price Index) is consistently in an upward direction.

Measurement Submodel

$$\begin{bmatrix} UVR \\ PSHIP \\ TFP \end{bmatrix} = \begin{bmatrix} 0 & 1 & \lambda_1 & 1_* \\ 0 & 1 & \lambda_2 & P^*_* \\ v_1 & 0 & 1 & Z^* \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix}$$

Structural Submodel

$$\begin{bmatrix} P^* \\ Z^* \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ \alpha_1 & \gamma_1 & \gamma_2 & \gamma_3 \end{bmatrix} \begin{bmatrix} ORND \\ USED \\ PROP \end{bmatrix} + \begin{bmatrix} \zeta_1 \\ \zeta_2 \end{bmatrix}$$

or in equation form,

$$UVR = P^* + \lambda_1 Z^* + \varepsilon_1 \tag{3}$$

$$PSHIP = P^* + \lambda_2 Z^* + \varepsilon_2 \tag{4}$$

$$TFP = v_1 + Z^* + \varepsilon_3 \tag{5}$$

$$P^* = \zeta_1 \tag{6}$$

$$Z^* = \alpha_1 + \gamma_1\, ORND + \gamma_2\, USEDPR \text{ (or } \gamma_2'\, USEDPU) + \gamma_3\, PROP + \zeta_2 \tag{7}$$

UVR[1] is the Unit Value Relative compiled by the U.S. Bureau of the Census. Equation (3) is needed in order to have the model identified. UVR is defined as the ratio of the value of shipments to the corresponding quantity compared in two periods. PSHIP is the shipments deflator based on the producer price index (PPI) generated by the Bureau of Labor Statistics (BLS).[2] PSHIP has been used to obtain real shipments for the productivity figures of this paper.

Equations (3) and (4) specify UVR and PSHIP as indicators of P^* following the specification of equation (1).

Equation (5) expresses TFP growth rate as an indicator of quality-change, Z^*. TFP growth measures technical advance which is closely related to quality improvement. The intercept term v_1 expresses a measurement bias which is discussed in Section IV. The

---

[1]. Empirical variables are fully discussed in the next section.

[2]. See Gray [1989].

random variables ε_1, ε_2, and ε_3 reflect measurement errors due to unaccounted quality change. Equation (6) specifies "true" price change, P^*, as a stochastic exogenous variable.

Finally, equation (7) expresses product-quality change as a function of four different variables of R&D intensity based on Scherer [1984]. ORND and USED refer to expenditures for product-oriented R&D performed: (a) within the industry (ORND); and (b) by the industry's suppliers of equipment and materials (USED). USED R&D is further distinguished between the "private" goods' and "public" goods' concepts. According to Scherer [1984, pp. 432-435] "...R&D dollars or patents were flowed out to using industries in such a way that the sum of the flows equalled the sum of the origin industry's R&D....For any patent covering consumer goods the final consumption sector column received the full R&D cost of that patent whether or not there were also industrial uses. In effect, the consumer goods applications of such inventions were treated as public goods not reducing the amount of R&D available for transmission to industrial sectors.". PROP refers to processed patents which is used as a proxy for process R&D. A positive and significant relationship is expected between Z^* and all R&D intensities.

Equations (5) and (7) imply the traditionally accepted relationship between TFP growth and R&D intensity given by the following equation:

$$f = \lambda + \rho(R / Q) + u \tag{8}$$

f is the rate of growth of TFP; λ is the disembodied technical change; ρ is the rate of return to R&D expenditures, R, provided that the rate of obsolescence of the R&D capital, is small. Q is output and u is a random disturbance term.

Equation (8) lies within the theoretical framework of the Cobb-Douglas production function. The assumptions made are separability of the conventional inputs from the R&D capital, constant returns to scale for the conventional inputs, and equality of their marginal products to their respective remuneration.

Thus, the rate of growth in productivity depends indirectly, through quality-change, on the intensity of R&D investment. Accordingly, the empirical variables ORND and USED are intensities of R&D expenditures over shipments.

III. THE DATA

The major sources of the data in this paper are the following:

(1) The Special Census Deflator Comparison File that was provided by the Industry Division of the Census Bureau. It contains data at the seven-digit SIC product level on the value of shipments for the years 1977 and 1982, the UVR, the producer price index and other price indexes.

(2) The technology flow matrix of Scherer [1984]. It contains various components of R&D expenditures at the four-digit SIC industry level.

(3) The Wayne Gray Productivity Database File at the NBER (National Bureau of Economic Research). It contains data on PSHIP and other price deflators, TFP growth, as well as annual output and input measures, all at the four-digit SIC manufacturing industries during the years 1958-1989. The NBER File is an updated version of the Penn-SRI Database created at the Census Bureau in the late seventies and is described in full detail in Griliches and Lichtenberg [1984a].

For the construction of UVR, due to its definition as the ratio of the value of shipments to corresponding quantity between two periods, invoice data are used as they are, and then they are divided by the corresponding quantity. Thus, while the UVR is based on transaction prices, it is, however, characterized by lack of homogeneity in its mix of products, leaving the UVR not even partially quality-adjusted (see, for instance, Gordon [1990, p. 15] and Lichtenberg and Griliches [1989, Table 1, p. 3]). On the other hand, for the construction of PSHIP (PPI) various methods have been followed[1] which theoretically try to adjust for quality-change. Thus, one would expect PSHIP to be less biased than UVR.

TFP growth, in the Gray File at the NBER, is measured as the growth rate of output (real shipments) minus the cost-share-weighted average of the growth rates of each of the five inputs (production workers, non-production workers, non-energy materials, energy, and capital). The cost shares are taken from the ASM (Annual Survey of Manufactures) data on the expenditures for each input, divided by the industry's value of shipments (and averaged between the current and previous year). Capital's cost share is calculated as a residual, so the cost shares add to 1. The labor inputs are measured in real terms as the number of production worker hours and number of non-production workers.

The empirical variables are available at the four-digit industry level, except for the UVR which is available at the seven-digit product level. Thus, in order to match the data, those reported in the Special Census Deflator Comparison File were aggregated to the four-digit industry level by computing weighted averages of (seven-digit) product UVR's using value of

---

[1]. See Gordon [1990, pp. 79-107], and U.S. Department of Labor, Bureau of Labor Statistics [1986].

product shipments as weights.

Summary statistics for the resulting sample of 279 industries for which data for all the variables were available are presented in Table 1.

TABLE 1
Four-Digit Manufacturing Industries:
Summary Statistics for the 279 Sample Industries
1977-1982

Variable	Mean	St.Dev.	Minimum	Maximum
UVR	0.3679	0.1933	-.4797	0.9274
PSHIP	0.3527	0.1580	-.6916	0.8965
TFP	0.0035	0.0261	-0.0616	0.1789
ORND	0.0112	0.0147	.0000	0.1126
USEDPR	0.0055	0.0049	.0007	0.0268
USEDPU	0.0190	0.0144	.0042	0.2057
PROP	0.3818	0.3012	.0000	1.0000

Notes:

(1) UVR, PSHIP, and TFP are in logarithmic changes.

(2) ORND and USED are intensities over shipments.

(3) USEDPR and USEDPU denote USED R&D, the private and public goods' concepts respectively.

(4) PROP is a fraction.

IV. THE MAXIMUN LIKELIHOOD ESTIMATES

Table 2 presents six different versions of the maximum likelihood estimates of equations (3)-(7). This model was estimated using the LISREL approach with intercept terms. Under the assumptions that $cov(\varepsilon_i, \varepsilon_j) = 0$, $(i, j = 1, 2, 3; i \neq j)$; $cov(\zeta_1, \zeta_2) = 0$, this system is subject to four overidentifying restrictions. There are 21 sample moments and 17 free parameters to be estimated. The 17 free parameters are the six coefficients of the equations (3) - (7), five variances of the error terms, plus the covariance matrix of the observed independent variables. v_1 has been fixed to -0.05 implying that TFP growth is .05 units lower, on average, than the true product-quality change, Z^*. This value is based on Lichtenberg and Griliches [1989], who found that during 1972-1977 product quality increased by about 4.5% on average. Consequently, it is assumed that during 1977-1982 the average quality improvement should be at least .05. However, values lower as well as higher than .05, in the range of .01 to .10, were also tried, but the fit of the model did not show any significant improvement. So the value -.05 was finally retained.

Equation (7), when the intercept term was included, gave imprecise or inadmissible (negative estimated variances) results. The model has also been estimated by relaxing the assumptions of orthogonality of disturbances between equations (4) and (5), and (6) and (7). Thus, the ML estimate of $cov(\varepsilon_2, \varepsilon_3)$ is 0.000386 (0.000657), and of $cov(\zeta_1, \zeta_2) \neq 0$ is 0.0024 (0.0037) - standard errors in parentheses. These results showed a non-significant relationship, implying that the orthogonality assumptions did not violate the data.

The evaluation of the overall fit of the model is achieved with two measures, the GFI and the RMSR.[1] The goodness-of-fit index, GFI, is independent of the sample size and relatively robust against departures from normality, and it should be between zero and one. The root mean square residual, RMSR, can be used to compare the fit of two different models for the same data.

As Table 2 shows, all estimated versions of the model have a satisfactory fit. The estimated effects of the R&D variables on quality change are as expected. ORND, USEDPR, USEDPU and PROP all have positive and significant effects on Z^* directly, and indirectly on TFP growth in all tried versions of the model. USEDPR has a stronger effect than USEDPU or any other R&D variable. This result agrees with Scherer [1984, p.449], who found that R&D flows under the public goods' approach had "appreciably less explanatory power" than R&D flows under the private goods' approach. Lichtenberg and

[1]. See Joreskog and Sorbom [1989, pp. 26-27].

TABLE 2

Maximum Likelihood Estimates of Model (3)-(7)

Model Versions: Parameters	1	2	3
λ_1	6.8181	7.2910	6.6731
	(0.4970)	(0.4625)	(0.3860)
λ_2	5.7241	6.5009	6.0455
	(0.4903)	(0.4377)	(0.3658)
v_1	-0.05	-0.05	-0.05
γ_1	1.9255	-	-
	(0 .1556)		
γ_2		5.4134	3.1242
	(0.3593)	(0.3658)	
γ_2'	-	-	
γ_3	-	-	0.0569
			(0.0055)
$\sigma^2_{\epsilon 1}$	0.0114	0.0151	0.0181
	(0.0032)	(0.0032)	(0.0032)
$\sigma^2_{\epsilon 2}$	0.0213	0.0189	0.0164
	(0.0033)	(0.0031)	(0.0030)
$\sigma^2_{\epsilon 3}$	0.0008	0.0011	0.0008
	(0.00017)	(0.0001)	(0.0001)
$\sigma^2_{\zeta 1}$	0.0360	0.0249	0.0341
	(0.0073)	(0.0059)	(0.0052)
$\sigma^2_{\zeta 2}$	0.0015	0.0009	0.0006
	(0.0002)	(0.0001)	(0.0001)
df	13	13	12
GFI	0.619	0.668	0.710
RMSR	0.124	0.121	0.121

Notes:

(1) Standard errors are in parentheses; df denotes "degrees of freedom".

Model Version: Parameters	4	5	6
λ_1	7.3301	6.7540	6.2329
	(0.4431)	(0.3782)	(0.3875)
λ_2	6.6243	6.2471	5.5383
	(0.4183)	(0.3532)	(0.3700)
v_1	-0.05	-0.05	-0.05
γ_1	-	-	-
γ_2	-	-	-
γ_2'	1.7689	1.2035	-
	(0.1055)	(0.0905)	
γ_3	-	0.0530	0.0912
	(0.0044)	(0.0049)	
$\sigma^2_{\epsilon 1}$	0.0167	0.0204	0.0168
	(0.0031)	(0.0031)	(0.0033)
$\sigma^2_{\epsilon 2}$	0.0176	0.0145	0.0174
	(0.0030)	(0.0028)	(0.0032)
$\sigma^2_{\epsilon 3}$	0.0011	0.0009	0.0006
	(0.0001)	(0.0001)	(0.0001)
$\sigma^2_{\zeta 1}$	0.0235	0.0321	0.422
	0.0053)	(0.0047)	(0.006)
$\sigma^2_{\zeta 2}$	0.0007	0.0003	0.0010
	(0.0001)	(0.00008)	(0.0001)
df	13	12	13
GFI	0.676	0.735	0.665
RMSR	0.122	0.121	0.121

Notes: (1) Standard errors are in parentheses; df denotes "degrees of freedom".

Griliches [1989] have also found a stronger effect of USEDPR (their SUP.RD) than ORND (their OWN.RD). The results give also support to the belief of Lichtenberg and Griliches [1989, p.7], that "the major cause of quality change is product-oriented (as opposed to process-oriented) R&D expenditures...", although they do not include a process-oriented R&D variable in their model.

In particular, the rate of return to product-oriented R&D is in all cases significantly higher than unity. In model version 2, the rate of return to USEDPR, γ_2, is estimated at a high 5.41. In general, the estimated effects of R&D intensities on TFP growth are stronger and/or more significant in this study than in previous studies at both, the firm and industry level. Mairesse and Sassenou [1991] in a comprehensive survey of the R&D and productivity relationship at the firm level report estimated rates of return to R&D and output R&D elasticities well below unity. At the industry level, a lot of work has been done by Griliches.[1] For the periods 1959-1963 to 1964-1968, 1964-1968 to 1969-1973, and 1969-1973 to 1974-1976 the estimated rates of return to R&D were found strong and significant, but with a poor single equation regression fit.

Regarding the rest of the estimates in Table 2, the measurement error variances are all statistically significant at the 5% level implying the presence of high measurement errors. In addition, the estimates of λ_1 and λ_2 are significantly different from zero and one. Besides, the sample mean difference between UVR and PSHIP is 0.0152 which is not statistically different from zero at the 5% ($t=1.35$, $Pr > |t| = 0.1776$). Thus, the two deflators, UVR and PSHIP, not only do they not adjust for product quality change, but they also distort true price change to a very significant extent, according to section II. This happens despite the use of the revised 1982 price data.[2]

---

[1]. See, for example, Griliches [1980]; Griliches and Lichtenberg [1984a,b].

[2]. The Bureau of Labor Statistics (BLS) started a major revision of the PPI in 1978. See U.S. Department of Labor [1986]. Consequently, one would expect PSHIP, which is based on PPI (Gray [1989]), to partially adjust to quality change, or at least represent true price change much closer than UVR which includes "mix of products of varying degrees of homogeneity" (Lichtenberg and Griliches [1989, Table 1, p.3]).

V. CONCLUDING REMARKS

This article dealt with the development of a linear structural relations model to estimate the indirect effects, through product quality-change, of four different variables of R&D intensities on total factor productivity (TFP) growth. The model was applied to 279 U.S. manufacturing industries for the time span 1977-1982.

The paper has focussed on a more realistic structural representation of the direct effect of product-quality change on TFP growth, by considering product quality-change as a stochastic conceptuous variable, as well as by introducing measurement errors of TFP figures and output deflators into the model.

Within this framework, the ML estimate of the rate of return to product-oriented R&D is significantly above unity, with that of R&D performed by the industry's suppliers of materials and equipment reaching 4.5. This finding gives further evidence of strong interindustry R&D spillovers.

From another perspective, this paper can be considered as giving further stronger support to those who believe that measurement errors may be a very significant source of explanation of the "productivity puzzle".

REFERENCES

Baily, M.N. and Gordon, R.J. (1988). "Measurement Issues, the roductivity Slowdown, and the Explosion of Computer Power", Brookings Papers on Economic Activity, No.2.

Bollen, K.A. [1989]. Structural Equations with Latent Variables, New York: John Wiley & Sons.

Denison, Edward, F. [1957]. "Theoretical Aspects of Quality Change, Capital Consumption, and Net Capital Formation", in Modigliani, Franco (ed.), Problems of Capital Formation, Studies in Income and Wealth, No. 19, pp.215-36, Princeton University Press, for the NBER.

______ [1971]. "Welfare Measurement and the GNP", Survey of Current Business, 51, pp.1-8.

Fischer, S., [1988]. "Symposium on the Slowdown in Productivity Growth", Journal of Economic Perspectives, Vol.2, No.4, pp. 3-7.

Gordon, Robert, J. [1971]. "Measurement Bias in Price Indexes for Capital Goods", Review of Income and Wealth, Ser.17, No.2, pp. 121-174.

______ [1990]. The Measurement of Durable Goods Prices. University of Chicago Press, for the NBER.

Gray, W. [1989]. "Productivity Data Base", Internal Document, NBER, June.

Griliches, Z. [1971](ed.). Price Indexes and Quality Change: Studies in New Methods of Measurement, Cambridge, MA: Harvard University Press.

_____ [1973]. "Research Expenditures and Growth Accounting", in Williams, B.R. (ed.), Science and Technology in Economic Growth, London, pp. 59-95.

[1979]. "Issues in Assessing the Contribution of R&D to Productivity Growth", The Bell Journal of Economics, Spring Vol.10, No.1, pp. 92-116.

_____ [1980]. "R&D and the Productivity Slowdown", American Economic Review, Vol.70, No.2, pp. 343-348.

_____ [1987]. "R&D and Productivity: Measurement Issues and Econometric Results", Science, Vol.237, pp. 31-35.

_____ [1988]. "Productivity Puzzles and R&D: Another Nonexplanation", Journal of Economic Perspectives, Vol.2, No.4, pp. 9-21.

_____ [1989]. "Patents: Recent Trends and Puzzles", Brookings Papers on Economic Activity, Microeconomics, pp. 291-319.

_____ [1990]. "Hedonic Price Indexes and the Measurement of Capital and Productivity: Some Historical Reflections", in Berndt, E.R. and Triplett, J. (eds.), Fifty Years of Economic Measurement, NBER, Studies in Income and Wealth, Vol. 54, pp.185-206.

_____ [1991]. "Productivity and Technological Change: Some Measurement Issues", Technology and Productivity, OECD, Paris, pp. 229-231.

Griliches, Z. and Lichtenberg, F. R. [1984a]. "R & D and Productivity Growth at the Industry Level: Is there Still a Relationship?", in Griliches, Z. (ed.), R & D, Patents, and Productivity, Chicago: University of Chicago Press, pp. 465-496.

_____[1984b]. "Interindustry Technology Flows and Productivity Growth: A Reexamination", The Review of Economics and Statistics, Vol.66, pp. 324-329.

Hayduk, L.A. [1987]. Structural Equations Modeling with LISREL, The John Hopkins University Press, Baltimore.

Jorgenson, Dale, W. and Zvi Griliches [1967]. "The Explanation of Productivity Change", Review of Economic Studies, 34, pp. 249-283.

Joreskog, K.G. and Sorbom, D. [1989]. LISREL VII, Manual, Scientific Software Inc., Chicago.

Larsgaard, O. A. and L. J. Mack [1961]. "Compact Cars in the Consumer Price Index", Monthly Labor Review, 84, pp. 519-523.

Lichtenberg, F.R. and Griliches, Z. [1989]. "Errors of Measurement in Output Deflators", Journal of Business and Economic Statistics, Vol.7, No.1, pp. 1-9.

Mairesse, J. and Sassenou, M. [1991]. "R&D and Productivity: A Survey of Econometric Studies at the Firm Level", NBER Working Paper No. 3666.

Price Statistics Review Committee [1961]. "The Price Statistics of the Federal Government", NBER, General Series, No. 73.

Scherer, F. M. [1984]. "Using Linked Patent and R&D Data to Measure Interindustry Technology Flows", in Griliches, Z. (ed.), R & D, Patents, and Productivity, Chicago: University of Chicago Press, pp. 417-461.

U.S. Department of Labor, Bureau of Labor Statistics [1986]. Producer Price Measurement: Concepts and Methods, Washington, D.C., June.

Triplett, J. [1970]. "The Quality Problem: A Survey of Empirical Studies Relating to Quality Bias in Price Indexes", Discussion Paper, Department of Economics, Washington University, St. Louis, September.

______ [1971]. "The Theory of Hedonic Quality Measurement and its Use in Price Indexes", U.S. Bureau of Labor Statistics, Staff Paper no.5, U.S. Government Printing Office.

______ [1983]. "Concepts of Quality in Input and Output Measures: A Resolution of the User-Value/Resource-Cost Debate", in Foss, M.F. (ed.), The U.S. National Income and Product Accounts: Selected Topics, Conference on Research in Income and Wealth, Studies in Income and Wealth, Vol.47, University of Chicago Press for the NBER, pp. 296-311.

_____ [1988]. "Price Index Research and Its Influence on Data: A Historical Review", paper presented at the NBER Conference on Prices, Cambridge, MA, May 1988.

_____ [1990]. "Hedonic Methods in Statistical Agency Environments: An Intellectual Biopsy", in Berndt, E.R. and Triplett, J. (eds.), Fifty Years of Economic Measurement, Studies in Income and Wealth, Vol. 54, NBER, pp. 207-237.

IN THE SAME SERIES

No 1 G. Alogoskoufis, Competitiveness, Wage Rate Adjustment and Macroeconomic Policy in Greece. Athens, 1990 (in Greek).

No 2 L. Athanassiou, Adjustments to the Gini Coefficient for Measuring Economic Inequality. Athens, 1990.

No 3 J. Dutta and H. Polemarchakis, Credit Constraints and Investment Finance: Evidence from Greece. Athens, 1990.

No 4 C. Kanellopoulos, The Underground Economy in Greece: What Official Data Show. Athens (in Greek 1990 - in English 1992).

No 5 N. Antonakis and D. Karavidas, Defense Expenditure and Growth in LDCs - The Case of Greece, 1950-1985. Athens, 1990.

No 6 J. Geanakoplos and H. Polemarchakis, Observability and Constrained Optima. Athens, 1992.

No 7 L. Athanassiou, Distribution Output Prices and Expenditure. Athens, 1992.

No 8 N. Christodoulakis, Certain Macroeconomic Consequences of the European Integration. Athens, 1992.

No 9 V. Rapanos, Technological Progress - Income Distribution and Unemployment in the less Developed Countries. Athens, 1992.

No 10 V. Rapanos, Joint Production and Taxation. Athens, 1992.

No 11 D. Maroulis, Economic Analysis of the Macroeconomic Policy of Greece during the Period 1960-1990. Athens, 1992 (in Greek).

No 12 C. Kanellopoulos, Incomes and Poverty of the Greek Elderly. Athens, 1992.

No 13 G. Agapitos and P. Koutsouvelis, The Harmonization within EEC: Single Market and its Impacts on Greece's Private Consumption and Vat Revenue. Athens, 1992.

No 14 C. Carabatsou-Pachaki, Elaboration Principles/Evaluation Criteria for Programmes. Athens, 1992 (in Greek).

No 15 C. Carabatsou-Pachaki, Reforming Common Agricultural Policy and Prospects for Greece. Athens, 1992 (in Greek).

No 16 P. Paraskevaides, Effective Protection, Domestic Resource Cost and Capital Structure of the Cattle Breeding Industry. Athens, 1992 (in Greek).

No 17 Kl. Efstratoglou, Export Trading Companies: International Experience and the Case of Greece. Athens, 1992 (in Greek).

No 18 C. Carabatsou-Pachaki, Rural Problems and Policy in Greece. Athens, 1993.

No 19 St. Balfoussias, Ordering Equilibria by Output or Technology in a Non-linear Pricing Context. Athens, 1993.

No 20 St. Balfoussias, Demand for Electric Energy in the Presence of a two-block Declining Price Schedule. Athens, 1993.

No 21 P. Paraskevaides, Regional Typology of Farms. Athens, 1993 (in Greek).

No 22 P. Paraskevaides, Evaluation of Regional Development Plans in the East Macedonia-Thrace's and Crete's Agricultural Sector. Athens, 1993 (in Greek).

No 23 C. Eberwein and Tr. Kollintzas, A Dynamic Model of Bargaining in a Unionized Firm with Irreversible Investment. Athens, 1993.

No 24 P. Paraskevaides, Income Inequalities and Regional Distribution of the Labour Force Age Group 20-29. Athens, 1993 (in Greek).

No 25 A. Gana, Th. Zervou and A. Kotsi, Poverty in the Regions of Greece in the late 80's. Athens, 1993 (in Greek).

No 26 G. Georganta, The Effect of a Free Market Price Mechanism on Total Factor Productivity: The Case of the Agricultural Crop Industry in Greece. Athens, 1993.

No 27 H. Dellas, Recessions and Ability Discrimination. Athens, 1993.

No 28 Z. Georganta. Accession in the EC and Its Effect on Total Factor Productivity Growth of Greek Agriculture. Athens, 1993.

No 29 H. Dellas, Stabilization Policy and Long Term Growth: Are they related?. Athens, 1993.

No 30 Z. Georganta, Technical (In)Efficiency in the U.S. Manufacturing Sector, 1977-1982. Athens, 1993.

No 31 P. Paraskevaidis, The Economic Performance of the Agricultural Cooperative Organisations. Athens, 1993 (in Greek).