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Verdoorn-Kaldor's Law: an empirical analysis with time series data in the United States

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Abstract

Verdoorn's law refers to a statistical relationship between the long-run growth rate of labour productivity and the growth rate of output, usually for the manufacturing sector. Since the sixties this relationship has been examined in a large number of studies using a wide variety of data sets and employing different econometric models. This paper is based on a time series analysis and formulates the law in terms of cointegration and Granger-causality between manufacturing output and labour productivity. Quarterly U.S. data for 1987-2007 is used to test the pattern implied by the law. Results show that manufacturing production and labour productivity are variables that are integrated of order (1,1), and are also cointegrated. The impulse response function shows that a shock on one variable has a positive impact on the other variables.

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1 Introduction

Around fifty years ago, the Dutch economist P.J. Verdoorn [24] published the results of his research on productivity and output growth in an article entitled "Fattori che regolano lo sviluppo della produttività del lavoro" in the Italian journal *L'Industria*. Verdoorn refers to a statistical relationship between the long-run growth rate of labour productivity and the growth rate of output, particularly in the manufacturing sector. The relationship is generally interpreted as being of a technological nature, thus reflecting the existence of both static and dynamic economies to scale and increasing returns [3].

Afterwards Kaldor [15] in his work on alternative theories of distribution first introduced Verdoorn's law in order to explain the causes of the United Kingdom's slow rate of economic growth. Kaldor [15, 16] gives a new meaning to the original Verdoorn Law, which was based only on the assumption that it is productivity growth that determines output growth, by stating that this relationship is a dynamic rather than static one: since it involves "technical progress" it is not just a reflection of the economies of larger production. Since Kaldor's seminal work in 1966 the relationship has been renamed Verdoorn–Kaldor's law. The importance of Verdoorn–Kaldor's law is that it highlights that industry is subject to increasing returns to scale, both static and dynamic.

The law has been investigated in a large number of studies, employing different econometric methods, mainly parametrics [13], at different levels of analysis: i.e. cross-country or cross-region, inter-industry and time-series for countries and regions. A variety of econometric techniques have been used including OLS, instrumental variable techniques, time-series, error correction models and cointegration methods. The earlier studies encountered a number of statistical and econometric problems. The biggest problem with Verdoorn's law is the potential problem of bias due to simultaneity between the two variables. A problem has also arisen over the direction of causality [20].

Harris and Liu [12] identify three other problems. The first is that the law ignores the contribution of capital, which can be substituted with labour, thus implying that the Verdoorn coefficient is not stable since the elasticity of capital with respect to labour is not constant. The second problem is whether output (employment or productivity) is endogenously or exogenously determined. The third problem is the apparent paradox when measuring static or dynamic scale economies. In fact, different values of the Verdoorn coefficient (and thus increasing returns to scale) are often obtained when estimating a linear model in static terms (variables in levels) or dynamic terms (variables in first differences). McCombie [18] suggests that this may be because the true specification of the underlying static model should be a nonlinear (technical progress) function rather than the usually assumed linear Cobb–Douglas production function. This apparent static–dynamic paradox can also be related to the dynamic specification of the empirical model to be estimated when times series data is used. Whatever approach is adopted, it is necessary to ensure that the empirical model adequately captures the underlying dynamic processes in the data (especially for the static model), otherwise the results will be biased [14].

In this work, to overcome the static–dynamic paradox and the direction of causality problem, we formulate the law in terms of cointegration and Granger-causality, then test it with quarterly U.S. data for the 20-year period 1987-2007. This work is structured in the following way. In the second section Verdoorn's law is introduced. In the third section some empirical studies are presented. The fourth and fifth sections present the empirical approach and data used. Finally, the results and the conclusion are shown.

2 Verdoorn's Law

Verdoorn's law postulates the existence of a significant positive relationship between the growth rate of labour productivity and that of output, with particular reference to the manufacturing sector. The relationship can be expressed in the following way:

$$P = \alpha + \beta Q + \varepsilon \qquad \beta > 0 \tag{1}$$

where P and Q are labour productivity and output in the manufacturing sector, respectively: β is Verdoorn's coefficient, which is positive and suggests that a rise in output causes an improvement in labour productivity and a fall in output results in a decline in labour productivity, ε is the error term.

The relationship is generally considered to be of a technological nature, thus reflecting the existence of both static and dynamic economies of scale, and hence of increasing returns. In fact, while Verdoorn's dynamic law (specified using growth rates) yields estimates of substantial increasing returns to scale, the Verdoorn's static law (specified using log-levels) indicates only the presence of constant returns to scale.

Kaldor [16] tested the validity of the law for a cross section of industrial countries in the 1953-1964 period, finding a value for Verdoorn's coefficient, i.e. the marginal elasticity of labour productivity with respect to output, of about 0.5. Since the marginal elasticity of employment, which by definition is the complement to that of the Verdoorn coefficient, had the same approximate value, Kaldor argued that a one percentage point increment in the growth of output required an increase in employment of only half that amount, while the rest was accommodated by an equal rise in productivity.

According to Kaldor [17], if β does not differ significantly from unity, then the hypothesis of "increasing returns to scale" is rejected. Kaldor emphasised the role of increasing returns to scale as the major source of differences in productivity growth rates.

3 Empirical Studies

Verdoorn–Kaldor’s law has been widely tested in a variety of ways. Cross-country studies were progressively abandoned in favour of cross-region or time series analysis, since it was recognised that they could give rise to spurious correlations, if the various countries involved had different technological features or experienced different phases of economic development [20]. Some of the principal works on Verdoorn–Kaldor’s law are displayed in Table 1. It is important to note that the first works on the law applied OLS estimation for cross-country or cross-region study. Conversely, the more recent literature uses other econometric techniques in order to solve the different problems found in the relationship.

For example Atesoglu [2], in order to apply Kaldor's laws to long-term economic growth, uses the annual growth of each variable employed in time-series analysis smoothed with a 16 moving average annual growth rate. He asserts that this procedure, by emphasizing long-term economic growth, is in line with Kaldor's laws and successfully mitigates the effects of short-term cyclical changes. His empirical results reveal that Kaldor's laws are compatible with economic growth in the United States. McCombie-De Ridder [19] estimate the law for the United States with time series data across regions and across countries. The results show a good fit with Verdoorn’s law, but they not cover Okun’s law. Bianchi [3] estimates the Verdoorn–Kaldor law in the traditional way and suggests that there are increasing returns to scale both for the economy as a whole and for all sectors.

The most recent work, which this study follows in part, is by Mohammadi and Ram [22], Hamalainen and Pehkonen [11] and Harris and Liu [12]. All of three formulate Verdoorn’s law in terms of cointegration and Granger causality. In the first two cases the evidence of cointegration is mixed and, even if it exists, the causal effect of output on productivity seems negative and certainly not positive. Hamalainen and Pehkonen [11] studied Verdoorn–Kaldor’s law for Denmark, Finland, Norway and Sweden. Their results show that the law is confirmed.

Table 1: Some studies on Verdoorn–Kaldor's law

Author(s), year	Method	Results	Country	Period	Data
Apergis and Zikos [1]	MVCEM	Productivity growth in Greek manufacturing appears to be strongly affected by the Verdoorn effect. The hypothesis of increasing returns to scale receives strong support.	Greek	1960-95	National Statistic Service of Greek
Atesoglu [2]	TS	"Results compatible with earlier cross-section state data reported by McCombie and de Ridder [19]"*.	USA	1965-88	Economic Report of president
Bianchi [3]	OLS	"Estimates of the traditional Verdoorn's Law suggest that there are increasing returns to scale both for the whole economy and for all its sectors. The use of a specification that includes capital growth confirms that the industrial sector exhibits increasing returns to scale over the whole sample period"*.	Italy	1951-97	..
Destefanis [4]	NPA	"The results obtained with a non-parametric frontier analysis point to the pervasive existence of increasing returns to scale across developed and developing countries, in sharp contrast with traditional parametric estimates obtained using the same data set"*	52 countries	1965-92	Penn World Table
Drakopoulos and Theodossiou [6]	TS	"Verdoorn's law is confirmed"*.	Greek	1967-88	OECD historical data
Fase and Van Den Heuvel [9]	CEM	Verdoorn's Law not supported in growth rates. Granger test leads to a confirmation of the causality implied by Verdoorn's Law. The direction of causality is confirmed as running from output growth to productivity growth*.	Quarterly data Netherlands	1968-87	BLS
Hamalainen and Pehkonen [11]	MVCEM	"Verdoorn's Law was confirmed, as in other previous analyses using international data. However, the static form of the law appeared not to be particularly well-identified"*.	Denmark, Finland, Norway and Sweden	1960-90	..
Harris and Liu [12]	MVCEM	The Johansen approach and the inclusion of the capital stock variable show increasing returns to scale for most countries	62 countries	1965-90	BLS
Jefferson, (1988) [14]	2SLS – TS	"The Verdoorn specification suffers from a failure to specify the economic process through which growth affects productivity"*.	..	1949-81	..
Kaldor [16]	AC	Substantial dynamic and static increasing returns to scale	12 OECD countries	1953-54 / 1963-64	OECD
McCombie and de Ridder [19]	AR AC TS	"The estimates largely confirm the cross-country results. Time-series data for manufacturing also provides a good fit for Kaldor's specifications of Verdoorn's Law, but cast doubts on whether this is capturing increasing returns to scale, as distinct from the short run Okun's Law"*.	USA	1947-63 1950-70 1953-78	1947-63 1950-70 1953-78
Mohammadi and Ram [22]	CEM	"The direction of causality in the Verdoorn's Law from output to productivity growth is not confirmed"*.	USA	1950-88	BLS
Timmer and Szirmai [23]	OLS	"Significant values for the Verdoorn's coefficient were found. When taking the highest value for the Verdoorn's coefficient of 0.53 (for machinery and transport equipment branch) as the base for comparison, only three branches (namely metal, non-metallic mineral products and electrical machinery) were significantly different"*.	Asian countries	1963-93	..
Verdoorn [24]	AC	"For industry as a whole, there exists a fairly constant relationship between the growth rate of labour productivity and output. No statistical test provided"*.	14 countries	Interwar period	..

* McCombie *et al*., [20]: 9-27; ** AC: across countries; TS: annual time series; MVCEM: multivariate cointegration estimation method; CEM: Cointegration Estimation Method.

However, the static form of the law does not appear to be particularly well identified. Fase and Van Den Heuvel [9] affirm that their statistical causality with the bivariate time series model does not support Verdoorn's law formulated in growth rates.

Finally, Destefanis [4] studied the law from a non parametric frontier analysis point of view in 52 countries for the period 1965-92. He found that the existence of increasing returns to scale existed across developed and developing countries.

4 Empirical Approach

In order to test Verdoorn–Kaldor's law a parametric time series analysis is used. The law is formulated in terms of cointegration and Granger causality between manufacturing output and labour productivity.

From the Verdoorn–Kaldor's relationship it is possible to predict that manufacturing output and labour productivity should be cointegrated variables. Moreover, the literature suggests that the relationship between the two variables should be of a long-run nature. This is coherent with the cointegration approach. In fact, the propriety of cointegration can be interpreted as a long-run equilibrium between the variables [8]. In particular, "….if x_t was not co-integrated, … the equilibrium concept has no practical implication" ([8], p. 253). Therefore, according to Mohammadi and Ram [22] it is natural to expect Verdoorn's law to have a representation in terms of cointegration between manufacturing output and productivity.

Econometric theory asserts that cointegration is needed for meaningful representation of long-run equilibrium between the two variables. Moreover, Verdoorn's law carries a stronger implication and implies that there should be Granger-causality, with a positive impact, from manufacturing output to labour productivity.

Engle and Granger [8] argue that as long as variables are cointegrated, causality has to exist at least in one direction. Following their methodology the direction of causality between output and productivity will be detected by using the error-correction model.

As an initial step in the cointegration method, stationarity tests must be performed for each of the relevant variables. There have been a variety of methods proposed for implementing stationarity tests and each one has been widely used in applied economics literature. However, there is now a growing consensus that the stationarity test procedure in Dickey and Fuller [5] is superior when compared to its alternatives as it assumes that the disturbance term is an i.i.d. process. Therefore, in this study, the ADF (Augmented Dickey-Fuller) test is used to check for the unit roots of the time series variables. In the second step, the Elliott *et al*. [7] approach is used. The following step is to check for the Cointegration between the two variables. In this case two possible alternatives can be used: the first one is the Granger stationarity test on the residuals calculated from the regression of labour productivity on output. The second is the Johansen test on the presence of cointegrating vectors and a VAR approach. The direction of causality between the two variables is studied with the error correction models. Finally, the impulse response function is presented in order to study the responsiveness of each variable indicated as an endogeneous shock.

5 Data and Descriptive Statistics

Manufacturing output is represented by the U.S: Bureau of Labour Statistics (BLS) index of real output in manufacturing (1992=100). Labour productivity is measured in terms of the index of real output per hour in manufacturing with the same base year[2].

All series are available from 1987 to 2007 in annually and quarterly form, and seasonally adjusted. The use of seasonally adjusted data does not invalidate the estimation since raw data may suffer from spurious regression problems. As the series used in this study are believed to be non-stationary and, consequently, incorrect, non-causality null distributions have been applied. In Table 2 the descriptive statistics of the data are shown.

To study the Verdoorn–Kaldor law logarithms are applied. There are several reasons for this. First of all because many economic series exhibit growth that is approximately exponential, that is, over the long run the series tends to grow by a certain average percentage per year: if so, the logarithm of the series grows approximately linearly. Another reason is that the standard deviation of many economic time series is roughly proportional to the standard deviation expressed in levels. That is, the standard deviation is well expressed as a percentage of the level of the series; if so, then the standard deviation of the logarithm of the series is approximately constant. In either case, it is useful to transform the series so that changes in the transformed series are proportional to changes in the original series, and this is achieved by taking the logarithm of the series.

Table 2: Sample summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Production	84	122.97	20.49	89.97	156.08
Labour productivity	84	127.65	30.68	86.56	188.77

[2] Data are available at the following link: http://data.bls.gov/cgi-bin/dsrv?pr

However, the most important reason is the link to Verdoorn's law and, in particular, with Verdoorn's static or dynamic law [21]. Verdoorn's dynamic law (specified using growth rates) yields estimates of substantial increasing returns to scale, while the static version (specified using log-levels) indicates only the presence of constant returns to scale.

6 Empirical Results

6.1 Unit roots

The first step of this analysis was to test the stability of each variable. In order to do this the Augmented Dickey-Fuller (ADF) and the Elliott, Rothenberg, and Stock (ERS) test were used. The results are shown in Table 3.

Table 3: Unit roots tests on manufacturing production and labour productivity

Variable	Variables in logarithms				Variables in first differences			
	ADF	Critical Value	ERS	Critical Value	ADF	Critical Value	ERS	Critical Value
Production	-1.75	-4.08 (1%)	-1.60	-3.64 (1%)	-4.30	-3.54 (1%)	-3.36	-2.61 (1%)
		-3.47 (5%)		-3.08 (5%)		-2.91 (5%)		-1.95 (5%)
Labour Prod.	-2.83	-4.08 (1%)	-1.01	-3.64 (1%)	-5.24	-3.54 (1%)	-3.62	-2.61 (1%)
		-3.47 (5%)		-3.08 (5%)		-2.91 (5%)		-1.95 (5%)

In this case the null hypothesis of non-stationarity cannot be rejected at any level of significance. For the ERS test the results are no different from the ADF test. This is the same for both variables. It is possible to conclude that the logarithm of production and manufacturing labour productivity is not stationary.

This is in accordance with the theory and also with the result that Mohammadi and Ram [22] found for the US economy in the period 1950-88.

Once it is checked that the variables are not stationary in level, tests with the variables in first difference are run in order to check the order of integration. In this case the null hypothesis of non-stationarity is rejected at every level of significance, both for the ADF and the ERS test.

The previous ADF results of the null hypothesis show that a single unit root exists in the level logarithm but not in the difference of each series. Thus it is possible to conclude that variables are both integrated of order 1.

6.2 Cointegration analysis

If the variables are both integrated of the same order it is possible to study the short and the long-run relationship between the logarithms of manufacturing production and the logarithms of labour productivity.

In order to study the cointegration two different procedures are used. The first one is the Engle-Granger stationarity test on the residuals calculated on the Verdoorn–Kaldor law. The second one is the Johansen test on the presence of cointegrating vectors, following a VAR approach. The Engle-Granger methodology is based on the plot of the residuals. The graph (not reported here) shows that there is a trend in the cointegrating relation. Then the next step is based on the analysis of the Johansen methodology (trace test and max test). The results are shown in Table 4. Since the value of the statistic exceeds the 10 percent critical value of the λ_{trace} statistics it is possible to reject the null hypothesis of no cointegration vectors. The same information came from the $\lambda_{\max}$ statistics. Then for the λ_{trace} there is one cointegration vector. And the same results are yielded for the $\lambda_{\max}$ statistics.

Table 4: Johansen tests for cointegration (λ_{trace} and $\lambda_{\max}$ tests)

Null Hypothesis	Alternative Hypothesis	Value	5% Critical Value	10% Critical Value
		λ_{trace}		
$r=0$	$r>0$	11.77	12.53	10.47
$r\le 1$	$r>1$	3.57	3.84	2.86
		$\lambda_{\max}$		
$r=0$	$r=1$	8.20	11.44	9.52
$r=1$	$r=2$	3.57	3.84	2.86

6.3 Error correction models and impulse response function

Granger [10] and Engle and Granger [8] argue that as long as variables are cointegrated, causality must exist at least in one direction. Following their methodology the direction of causality between labour productivity and production in the manufacturing sector can be detected by estimating the Error Correction Models (ECM). The results of ECM are shown in Table 5.

The table displays the value of beta, the long-run coefficient. This value is significant, meaning that there is a long run relationship in Verdoorn–Kaldor's law. Therefore, an increase in the output is able to cause an increase in labour productivity in the manufacturing sector. In other words, the β coefficient normally captures the adjustment from the long-run equilibrium relationship between the variables. If this adjustment is smooth, then it should hold that $|\beta|<1$.

Table 5: Error Correction Models

	Coefficient	p-value
Beta	-0.43	0.000

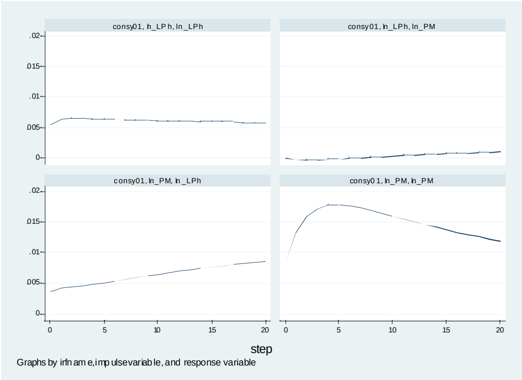

Figure 1: Impulse response function

The final step of this analysis is to study the impulse response function (IRF). The IRF refers to the time profile of the effect of a shock in the variable on the other variable in the model. In figure 1 it is possible to see that a shock has a positive impact on the other variable.

Thus it is possible to assert that manufacturing output and labour productivity variables are cointegrated and a shock in one variable has a positive influence on the other. However, the impulse-response functions for $LP \to PM$ and $PM \to LP$ do not converge back to zero, as they should, but remain positive and even seem to have a linear or increasing trend. This implies that a shock of productivity on itself or of output on productivity would have cumulatively increasing effects. In other words, a single shock suffices to trigger exponential increases in the levels of these variables. This could due to a possible source of error in the cointegration test. In fact, the null hypothesis of no cointegration of the Johansen test is rejected only at 10% level. So given its low power the chance of erroneously rejecting the null is high. This conclusion is the same as that made by Mohammadi and Ram [22] who found an unexpected positive sign on the error correction term.

7 Conclusion

In this paper the Verdoorn–Kaldor law is studied using the cointegration approach with quarterly BLS data from the United States from 1987 to 2007.

The first part of the empirical investigation has principally involved univariate time series analysis: stationarity of the key variables involved has been tested by Augmented Dickey-Fuller and Elliott, Rothenberg, and Stock procedures. The test fails to reject the null hypothesis of non-stationarity for both variables when they are expressed in logarithms. However the variables are stationary in the first difference, which brings the analysis back to Verdoorn's dynamic law. In fact, the first difference in logarithm could be approximate to growth rate.

The same order of integration for each of the two variables was a necessary condition to compute the core of this empirical analysis, i.e. to test the cointegrating relationship. Cointegration of order (1,1) was tested with Engle-Granger and the Johansen procedures. The results show evidence in favour of cointegration between the manufacturing output and labour productivity in the manufacturing sector. This is coherent with other econometric models that study the Verdoorn–Kaldor law with the same approach (i.e. Fase and Heuvel [9]; Mohammadi and Ram [22]).

The last step involves estimation of the error correction models relating the two variables and the impulse response function. The results show a positive relationship in the long run between the two variables. Also a shock in a variable can have a positive influence on the other variable. The results confirm that the Verdoorn-Kaldor's law holds in the United States during the period 1987–2007.

One way to improve this analysis would be to include the variable capital into the relationship as Kaldor [16] did using only with cross-country analysis.

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