Increasing returns to scale at the firm-level: a panel data study for Brazil

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Abstract: *This paper revisits Verdoorn's Law and issues related to its estimation using micro-data. Using a large panel of firms from the Brazilian manufacturing industry from 1996 to 2002, the exercise finds compelling evidence of increasing returns to scale in such a low level of aggregation using different specifications. The results were strengthened by indicator variables for sub-sectors and participation in foreign trade, included to test learning-by-doing process associated with trade. Finally, the regressions also showed a significant amount of regional variability of the Verdoorn coefficient.*

Key Words: increasing returns, Verdoorn, firms, manufacturing, Brazil.

JEL Classification: O12, R11, R30.

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1. Introduction

Since Kaldor's seminal works, Verdoorn's Law has been extensively estimated using a wide variety of datasets and countries. From an aggregate point of view, compelling evidence of increasing returns to scale has been found using either cross-section or time-series estimation. From a more disaggregated perspective, the estimation of the law for regional or sectoral data has also provided significant coefficients (McCombie et al., 2002). The estimation of Verdoorn's Law using spatial econometrics on regional data is a particularly fast growing area of application, as the importance of regional factors for productivity and output growth has been increasingly recognised (McCombie and Fingleton, 1998; Fingleton, 2000; Angeriz et al., 2006).

All estimations to date have, however, been constrained to some level of aggregation, either sectoral or regional. Kennedy (1971), for instance, departed from branch-level data, but further aggregated the original information into sectors of the Irish manufacturing industry before conducting his analysis. The use of aggregate datasets is, of course, perfectly justifiable given that the initial concern of cumulative causation models is to explain the disparity of growth rates between countries. Moreover, it was Kaldor's contention that increasing returns to scale are a macro-phenomenon and therefore should be estimated at the industry level using aggregated data (Kaldor, 1966).

Regardless of the source of the increasing returns, static or dynamic, external or internal, economies of scale can still be significant at the firm-level. Likewise, even if increasing returns stem from inter-industry specialisation, for instance, it does not mean that they cannot be measured at the firm-level. In this sense, our objective is to take a step further in disaggregation and use firm-level data. The use of micro-data has a number of practical advantages. The most important, given our objectives, is the freedom to control a larger number of variables for a much larger number of observations in comparison with traditional estimations. This is to say that, using the same dataset, it is possible to control for characteristics such as industrial sector and localisation, as well as for variables that indicate the firms' participation in foreign trade, still taking into consideration a high number of observations. From a statistical point of view, the use of micro data has the advantage of avoiding problems arising from the aggregation of individual firms into sectors or regions.

In the Brazilian case specifically, the ability to manipulate the data at the lowest level of aggregation represents a substantial advantage. To date, the estimation of Verdoorn's Law for the country has been constrained to cross-sectional regressions for aggregated data or to time-series regressions using high frequency data from the late seventies onwards. The results usually show a significant Verdoorn coefficient, but the level of aggregation prevents further insights regarding the determinants of growth. This shortcoming, inherent in macro-data, is of particular importance if one bears in mind the fact that the economic activity, as well as the population, is unevenly distributed across countries. Brazil is not an exception to this rule. Most of the population, and as a consequence, economic activities, is highly concentrated spatially.

In this paper we estimate Verdoorn's Law using a panel of firms from the manufacturing industry over the course of five years, from 1996 to 2002. Given the issues listed above and to enable the regression of more specifications, the panel was restricted to medium and large firms that employed more than thirty workers in the period. The panel was balanced, i.e., companies that were either created or left the survey during the period were excluded from the final sample.

The use of panel data has a few additional advantages for the estimation of Verdoorn's Law. First, it allows testing for the importance of both the cross-sectional and time-series dimensions of the data. Secondly, it allows testing for the importance of firm-specific characteristics by estimating either a fixed or a random effects model. In particular, this is important to exclude a possible bias caused by a heterogeneous level of technological development across the firms in the panel being captured by the Verdoorn coefficient.

The contribution of this paper to the literature is threefold. First, the estimation of different specifications of Verdoorn's Law using micro data can provide further evidence of a stable relationship between productivity growth and output growth. In addition, the use of micro-data will test if increasing returns to scale can be measured at the firm-level, using the highest number of observations to date. Secondly, even though the time-span of the data is relatively short, the panel-data estimations will test for the validity of the law for the Brazilian manufacturing industry in a period of intense structural change. The results of the regressions can be compared with the existing long-run estimations of the law using time-series. Thirdly, the use of disaggregated data and the panel data regressions will allow for a preliminary investigation into the factors affecting the rate of productivity growth and the level of the Verdoorn coefficient. The results obtained will serve as a guide for further exploration in the following chapters.

The chapter is divided in three sections apart from this introduction and some concluding remarks. Section 2 briefly describes some specification issues regarding the estimation of Verdoorn's Law and sets out the equations to be used in the regressions. Section 3 brings a review of the evidence available to date. Section 4 brings all the estimations' results. Brief concluding remarks follow.

2. Specification and issues

In spite of the simplicity of Kaldor and Verdoorn's original formulations, the estimation of the law has been subject to a number of empirical issues over the years. The preferred specification of Verdoorn's Law has been the subject of constant debate, which has led to significant changes from the seminal estimations to the most recent regressions. These issues have been discussed in detail over the years. An overview of the debate in each stage of the development of the literature can be found in McCombie and de Ridder (1984), Bairam (1987), McCombie and Thirlwall (1994), and more recently in the exhaustive review of the literature carried out by McCombie et al. (2002).

In this section, we briefly review some specification issues. Our objective is to set out the equations that will be used in the regressions as well as to place our contribution in relation to the literature rather than synthesising all the theoretical discussion and empirical applications to date. For this reason two important issues within the debate regarding the estimation of Verdoorn's Law are not dealt with in length in this chapter. The first is the classic debate between Rowthorn and Kaldor regarding the correct specification of Verdoorn's Law (Kaldor, 1975; Rowthorn, 1975a, 1975b). The second is the static vs. dynamic paradox, which arises from the estimation in levels or in growth rates providing distinct results. The search for an explanation for the paradox goes as far as McCombie (1981; 1982) and McCombie and de Ridder (1984). More recently, McCombie and Roberts (2007) proposed a solution for the paradox in which the static version of the law is mis-specified due to the presence of spatial aggregation bias in most datasets.[1]

The the original version of Verdoorn's Law according to Kaldor's (1966) interpretation is:

$$r_i = r_a + \lambda q_i \quad , \qquad (1)$$

where r_i, r_a and q_i are the rate of growth of productivity, autonomous productivity, and total output of the country, region or firm *i,* respectively.

The first problem that arises from this specification is the possibility of bias caused by spurious correlation between r_i and q_i. In this case, since $r_i = q_i - e_i$, the bias can be avoided by the use of the following specification:

$$e_i = \tau_a + \beta q_i \quad , \qquad (2)$$

where e_i is the rate of growth of employment and $\tau_a = - r_a$ and $\beta = (1-\lambda)$.

The estimation of equation (2) usually produces a coefficient of around one-half, providing evidence for the existence of increasing returns to scale. For Kaldor, an estimated coefficient (β) that is significantly less than 1 is a sufficient condition for the presence of both static and dynamic returns to scale. Otherwise, two options are possible. "First, that there is a significant relationship, but the coefficient of e and q is either not statistically different from unity or is significantly greater than unity. The later case is sufficient to reject increasing returns to scale" (Kaldor, 1975, p. 893).

Kaldor's preferred specification, given by equation (2), has been subject of an intense debate. The controversy was particularly intense during the seventies, with the famous debate between Rowthorn and Kaldor. According to Rowthorn, in Kaldor's original argument, the rate of output growth in the UK was constrained by labour shortages, in which case, the correct specification should use e_i, and not q_i, as regressor (Rowthorn, 1975a, 1975b). In this case, Rowthorn specification did not provide support for the prevalence of increasing returns to scale. Kaldor later withdrew his original

[1] Angeriz et al. (2006) offer new estimates of Verdoorn's Law using E.U. regional data. The use of a two-way estimation of the static specification showed increasing returns that were consistent with McCombie and Roberts' (2007) proposed solution.

claim, and justified his preferred specification on the grounds that output growth constrained by demand, not supply (Kaldor, 1975).

The problem of the correct specification still remains if both q_i and e_i are endogenous, in which case the estimated Verdoorn coefficient will suffer from simultaneous equation bias. A possible solution, originally suggested by McCombie (1981), involves using instrumental variables, but the results proved to be inconclusive (McCombie, 1997).

Black (1962) has pointed out that Verdoorn's Law can be derived from a conventional Cobb-Douglas production function if the rate of growth of capital stock is taken into consideration. In this case, equation (2) becomes:

$$e_i = a + \gamma q_i + \phi k_i \,, \qquad (3)$$

where k_i is the stock of capital. The degree of the returns to scale (υ) is given by $(1 - \phi)/\gamma$.

The estimation of (3) has provided poor results, with the coefficient for capital stock being statistically insignificant and/or showing the wrong sign. This was the case of McCombie and de Ridder (1983). The disappointing results are, according to the authors, likely to be caused by mis-specification, since the equation assumes the existence of both demand and supply constraints and that both q_i and k_i are exogenous.

A more realistic assumption is that the rate of growth of capital is endogenous, i.e., that the acquisition of capital is a function of anticipated output growth. In this case, both factors will be determined by the rate of growth of the output (McCombie and de Ridder, 1984; Bairam, 1987). This assumption is consistent with Kaldor's (1970) view that the growth of the capital stock is a function of the growth of the output. Hence, the preferred specification for Verdoorn's Law is:

$$f_i = \delta + \sigma_1 q_i \quad , \qquad (4)$$

where, f_i is the rate of growth of total factor productivity, given by:

$$f_i = \omega_i e_i + (1 - \omega_i) k_i \quad . \qquad (4a)$$

Equation (4a) represents the weighted rate of growth of total factor inputs, in which ω_i and $(1-\omega_i)$ are the shares of labour and capital on total output, respectively. In (4), the degree of the returns to scale is given by $1/\sigma_1$.

A common problem associated with (3) and (4) is the fact that reliable capital stock variables are very rarely available. A common alternative used by, amongst others, Cripps and Tarling (1973) and Kaldor (1978), is the investment to output ratio *(I/Q)* as a proxy for capital in aggregated regressions. This option is explained by the fact that $(I/Q)=(\Delta K/K)(K/Q)$. This proxy depends, however, on the capital to output ratio *(K/Q)* being constant (Bairam, 1987). Other options to estimate the capital stock are to use perpetual inventory techniques or to use cumulative gross investment (McCombie and de Ridder, 1984).

3. Evidence

As mentioned before, a number of works have applied Verdoorn's Law to test for the existence of increasing returns to scale and to show the validity of cumulative causation models. Since the original works of Verdoorn (1949) and Kaldor (1966), econometric techniques and the availability of data have significantly evolved. Bairam (1987) argued that three types of data have been used to estimate Verdoorn's Law: i) cross-sectional country data for total manufacturing or industrial output; ii) cross-sectional data for different regions within a country and iii) time-series data for total manufacturing or industrial output for a country.

Since the publication of Bairam's paper, the number of works estimating Verdoorn's Law has increased significantly. Most estimation and specification issues were addressed with the use of evolving econometrics techniques that became available. One example of this is the time-series estimation of the law for countries using cointegration. Another example of the growing number of applications is provided by studies that use developments of spatial econometrics techniques on increasingly available regional datasets, particularly for European Union countries. Again, a comprehensive review of the literature up to 2002 can be found in McCombie et al. (2002, pp. 9-27).

Considering our objectives, a few studies are worth mentioning, however. A first group includes works that used disaggregated data to estimate Verdoorn's Law by sector. In this group Kennedy (1971) is one the most notable examples, having estimated the law for 44 sectors of the manufacturing industry departing from firm-level data. The author found high and significant Verdoorn coefficients. McCombie and de

Ridder (1983) estimated Kaldor's Laws using U.S. regional data. The regressions using Kaldor's original specification arrived at a significant Verdoorn coefficient for all sectors included, with the exception of services. In the same paper, time-series regressions confirmed the good fit of the Verdoorn coefficient, but the coefficient for the growth of the capital stock was statistically insignificant and had the wrong sign.

McCombie and de Ridder (1984) widened the research using U.S. data and provided further evidence for the predominance of increasing returns to scale in the manufacturing industry, with estimates ranging from 1.33 to 1.65. The authors used an extended specification to include the growth of capital stock as well as total factor inputs. In addition, instrumental variables regressions were carried out to test for the significance of problems of simultaneity and measurement errors, but the estimated Verdoorn coefficients remained virtually unchanged. McCombie (1985) estimated several specifications of Verdoorn's Law for 17 manufacturing industries using U.S. data. The regressions showed significant coefficients for Verdoorn's specification in all industries and provided support for the contention that economies of scale arise from greater inter-industry specialisation.

Another important reference, this time for the use of spatial econometrics, is Bernat (1996), who tested Verdoorn's Law using U.S. data. Fingleton and McCombie (1998) and Pons-Novell and Viladecans-Marsal (1999) estimated the Verdoorn coefficient for E.U. regions. Fingleton (2000; 2001; 2003) extended the Verdoorn literature to incorporate new elements from, for instance, urban economics, using spatial econometrics on E.U. regional data.

From a panel data perspective, León-Ledesma (2000) estimated several specifications of Verdoorn's Law for a pool of seventeen Spanish regions. The author found strong support for the validity of the law, particularly for the preferred total factor inputs specification. León-Ledesma also successfully tested for increasing returns to scale in the services sector, while the results for agriculture did not show a significant relationship between total factor inputs and outputs.

More recently, Angeriz et al. (2006) provided new evidence for significant returns to scale in E.U. regions including a capital stock variable using a hybrid spatial model. The results were strengthened by the inclusion of a variable to capture technical change and a variable to capture agglomeration economies.

Specifically for Brazil, Verdoorn's Law was estimated as part of the studies using cross-section data, such as McCombie and Thirlwall (1994). Only two recent studies published recently have used exclusively data from Brazil, both using time-series estimation. Marinho et al. (2002) estimated the Verdoorn coefficient by fitting a VAR model using monthly data from 1985 to 1997. The authors used labour productivity and total output as variables and found a significant long-term relationship between the rate of growth of output and that of productivity. The estimated coefficient was remarkably close to Kaldor's seminal work, 0.45. The authors concluded that the significant coefficient is a sign that the manufacturing industry showed a remarkable level of dynamism during the period analysed.

The second study was carried out by Oliveira et al. (2006). The authors also fitted a VAR model to estimate the Verdoorn coefficient. In addition to the traditional variables, the authors included a variable to measure the technological gap between the country and the leading economy (U.S.A.). Using quarterly data from 1975 and 2000, the authors found a significant and high Verdoorn coefficient (0.70). The results were confirmed by impulse-response functions that showed that shocks in the rate of growth of output cause a permanent increase in the rate of growth of productivity. Regarding the gap variable, the estimated coefficient was significant and had the correct sign. However, its size was relatively small. In the author's assessment, this result shows that the technological gap does not constitute a considerable advantage in terms of productivity growth.

These two applications provide a good benchmark for the disaggregated regressions. In addition, the long-term results from each work raise some questions that can be addressed using firm-level data.

4. Data and Results

4.1 Data

All the variables used in the estimation of Verdoorn's Law (employment, output and capital stock) were obtained from the Annual Industrial Survey (PIA), published by the Brazilian Bureau of Geography and Statistics, from 1996 to 2002 (IBGE, several issues). Apart from the PIA data, three other database resources on firm-level information were used to create control variables by matching firms' codes. The first is the Foreign Trade Database from SRF. For tax purposes, SRF keeps detailed information of all firms' trade operations. Using the tax code, which is also used by PIA, it was possible to classify all the firms according to their foreign trade status and use the newly created variables as controls.[2]

To enable the regressions and at the same time guarantee the sample's representativeness, only medium and large firms were kept in panel. The final dataset consists in a balanced panel containing 6,027 firms, which, on average, represent around 87% and 83% of the manufacturing industry's total output and employment.

4.2 Results

a) Original specifications[3]

In the first round of regressions, original specifications of Verdoorn's Law were estimated using the full panel following the equations:

$$r_i = r_a + \lambda q_i \qquad (1)$$

$$e_i = \tau_a + \beta q_i . \qquad (2)$$

[2] It is important to stress that all information on individual firms is safeguarded by IBGE's and IPEA's strict rules of confidentiality. All data manipulation, carried at IBGE's facilities in Rio de Janeiro and all the output was subject to scrutiny to ensure that individual companies could not be singled out.

[3] In this paper we follow Kaldor's original view that output growth is demand constrained and, therefore, we use specifications of Verdoorn's Law in which the rate of growth of output is exogenous.

Table 1 – Verdoorn's Law: productivity and employment growth

	Productivity growth		Employment growth			
	(1) One-way FE –CS	(2) One-Way Random	(3) One-way FE-CS	(4) One-Way Random	(5) One-way FE-TS	(6) Two-way FE
q	0.388	0.274	0.612	0.726	0.718	0.602
	(32.20)	(25.40)	(50.70)	(67.10)	(66.40)	(49.90)
1997						0.002^{***}
1998						-0.005^{***}
1999						-0.001^{**}
2000						0.005^{***}
2001						0.001^{*}
Constant	-0.005	-0.005	0.005	0.005	0.005	0.005
	(-2.64)	(-2.54)	(2.64)	(2.54)	(2.56)	(2.66)
RS	1.63	1.38	1.63	1.38	1.39	1.66
R^2_{adj}	0.21	0.21	0.337	0.337	0.381	0.337
Hausman		453.53		453.53		
F-test[1]						67.71

Legend: RS: Returns to scale.
Figures in parentheses are t-ratios.
Note: [1] F-test of joint significance of time dummies.

The results for the regressions of the equations above are synthesised in Table 1 above. The table shows the results of specification using equation (2), for which a one-way fixed effects and a one-way random effects model were estimated (models 1 and 2), and of that using the rate of employment growth (equation 3), for which a one-way fixed effects for the time series component and a two-way fixed effects were also estimated (models 4 to 6). All the estimates for the Verdoorn coefficient are significant at 0.01% and have the correct sign. In addition, the Verdoorn coefficients for models 1 and 2 are, as expected, symmetrical to the coefficients from equations 3 and 4. For both specifications, a Hausman test shows that the fixed-effects is the preferred model and the R^2 from all models are compatible with the type of data used.[4] Finally, the estimated coefficients of the intercepts showed a negative growth of the autonomous productivity for all models. However, the coefficients are not statistically significantly different from zero. These counterintuitive results may be interpreted as reflecting the absence of productivity gains from technological change in the short time-span of the regressions.

[4] The Hausman test suggests that the individual slopes are not correlated with the regressors, the random-effects model being correctly specified. See Greene (2003).

Considering the regressions using the preferred specification with employment growth as the dependent variable (models 3 to 6), the estimated Verdoorn coefficients range from 0.27, for the random effects (model 4), to 0.40 for the two-way fixed-effects (model 6). These coefficients are associated with increasing returns to scale ranging from 1.38 to 1.66, respectively. The results of the F-test for the joint significance of the time dummies of the two-way fixed effects models together with the Hausman test show that model 6 is the best model.[5]

The level of the Verdoorn coefficient from model (6) is compatible with the results found in the literature. The comparison with the long-run estimates for Brazil using time-series show that the panel data estimation provided a coefficient reasonably close to that obtained by Marinho et al. (2002), estimated at 0.45, but significantly lower than the 0.70 estimated Verdoorn coefficient from Oliveira et al. (2006). One possible explanation for this discrepancy may be the distinct time-spans used by each study. While the first study uses data from 1985 to 1997, the second uses a larger span, from 1975 to 2000. The latter includes years of high growth rates from the seventies, resulting in higher average rates of productivity and output growth for the period as a whole.

b) Growth of capital stock

As discussed above, the basic specification of Verdoorn's Law is incomplete and can overestimate the Verdoorn coefficient, given that it does not account for the contribution capital to the rate of growth of productivity. To avoid this potential problem, the rate of growth of the capital stock was included in the equation.

The rate of growth of the consumption of electricity and fuel was used as a proxy, having tried without success to construct a capital stock variable that is reliable for a large number of firms. This is a second best solution, but there are at least two advantages of using this proxy. First, the number of firms that reported this variable in all years included in the panel is considerably higher than firms that declared all balance sheet variables needed to build the capital stock series. Secondly, the use of the proxy can contribute towards mitigating the estimation of a short-term cyclical relationship between the rate of productivity growth and that of output due to changes on the level of

[5] There are also theoretical reasons to choose the fixed-effects model for the regressions, given that characteristics that are common to some firms are captured by the constant (see Greene, 2003).

idle capacity, known as Okun's Law. In this case, the estimation of the Verdoorn equation can render a significant slope coefficient that has no relation to increasing returns to scale.

Ideally, this issue can be avoided through the use of hours worked for employment and utilised units, or output corrected by the level of capacity utilisation, for capital. However, this information is not available at the firm-level. Another possibility, according to McCombie et al. (2002), was suggested by Kaldor and involves the use of average growth rates for cross-sectional data over a longer period that starts and ends on peaks of the growth cycle. However, due to the short time-span of the dataset used in the estimations, this method is not viable. In our case, given that the use of energy consumption in a firm fluctuates according to production levels, he proxy for the rate of growth of the capital stock already accounts for variations in the rate of capacity utilization. Variations on the level of utilization of the labour force, however, remain unaccounted for.

The fist set of regressions including the capital stock proxy follows the equation:

$$e_i = a + \gamma q_i + \phi k_i \,, \qquad (3)$$

The results of the estimation including both factors of production can be seen in Table 2. Once more, the Verdoorn coefficient is highly significant for all models estimated. The coefficients for the capital stock variable are significant and have the correct sign, but are very low. Hence, the estimated levels of the returns to scale is similar to those from Table 1, ranging from 1.35 for the random-effects model to 1.64 for the two-way fixed-effects model. The latter is the preferred model, based on the Hausman test of fixed-effects and on an F-test for joint significance of the time dummies.

McCombie and de Ridder (1983) also obtained poor results for capital stock variables. The results from time-series regressions provided coefficients that were statistically insignificant and had the wrong size. The authors offered two possible explanations for the poor results for the capital stock variable. The first was simultaneous equation bias. IV estimation using lagged values of the regressors as instruments did not improve the results. The second explanation was the existence of adjustment lags between investment in new equipment and actual production. The use of lagged values of the capital stock as well as new IV regressions did not improve the results.[6]

Table 2 – Verdoorn's Law: factors contribution

	(1)One-way FE -CS	(2)One-way FE - TS	(3)Two-way FE	(4)One-Way Random
q	0.591	0.693	0.583	0.698
	(48.6)	(63.5)	(48.0)	(64.0)
k	0.045	0.052	0.042	0.055
	(12.1)	(14.8)	(11.4)	(15.4)
1997			0.001^{***}	
1998			-0.006^{***}	
1999			-0.001^{**}	
2000			0.005^{***}	
2001			0.001^{*}	
Constant	0.004	0.004	0.004	0.004
	(2.19)	(2.02)	(2.24)	(1.98)
RS	1.62	1.37	1.64	1.35
R^2_{adj}	0.420	0.352	0.353	0.353
Hausman				496.73
F-test[1]			64.25	

Legend: RS: Returns to scale = $(1-\gamma)/\phi$.
Figures in parentheses are t-ratios.
Notes: [1] F-test of joint significance of time dummies.

McCombie and de Ridder (1984) and Bairam (1987) offer another explanation for the poor performance of the capital stock variables in the estimation of Verdoorn's Law. According to the authors, the estimations in Table 1 assume that the rates of growth of both output and capital are exogenously determined. If, as advocated by Kaldor, the rate of growth of capital stock is endogenous, the poor results of the regression may be due to mis-specification.

With this in mind, the next set of estimations accounts for the endogeneity of the rate of growth of the capital stock. The estimated equation, which uses the rate of growth of total factor inputs as the dependent variable, is given by:

$$f_i = \delta + \sigma_1 q_i \quad , \qquad (4)$$

[6] To test for a possible bias caused by the endogeneity of the rate of growth of the output, IV regressions were carried out in the early stages of the regressions using Durbin's ranking method. The results (not reported) showed that the change of the estimated coefficients was negligible, similar to the estimations of McCombie and de Ridder (1983, 1984).

Table 3 – Verdoorn's Law: endogenous growth of capital

	(1) One-way FE -CS	(2) One-way FE - TS	(3) Two-way FE	(4) One-Way Random	(5) Two-way FE - HAR(1)
q	0.538	0.599	0.522	0.611	0.516
	(46.8)	(59.8)	(45.5)	(60.9)	(76.20)
1997			0.003^{***}		0.001^{***}
1998			-0.002^{***}		-0.002^{***}
1999			-0.003^{***}		-0.003^{***}
2000			0.006^{***}		0.006^{***}
2001			-0.001^{***}		0.001^{**}
Constant	0.001	0.001	0.001	0.001	0.001
	(6.7)	(7.0)	(6.8)	(6.9)	(13.1)
RS	1.86	1.67	1.92	1.64	1.94
R^2_{adj}	0.331	0.547	0.331	0.331	--
Hausman		170.02			
F-test[1]			78.31		1510.67
Wald heteroscedasticity χ^2=			0.000		0.000
Wooldridge autocorrelation χ^2=			0.000		0.054

Legend: RS: Returns to scale = ($1/\sigma$).
Figures in parentheses are t-ratios.
Notes: [1] F-test of joint significance of time dummies.

Once more, the results showed significant increasing returns to scale. However, in contrast with previous regressions, the estimated Verdoorn coefficients are significantly higher. As can be seen in Table 3 above, the level of the returns to scale ranged from 1.64 for the random-effects model (4) and the two-way fixed-effects model (3).

The final model in Table 3 is an attempt to correct for serial autocorrelation of the residuals and heteroscedasticity, which are common issues found in panel data regressions.[7] The Wald test for autocorrelation assumes homoscedasticity of the residuals of the cross-sectional units (firms). As can be seen in the table, the test

[7] One possible source of the heteroscedasticity is the spatial distribution of the firms. There are a few alternatives to account for this factor in the regressions. The first is to include a clustered structure to the residuals. This strategy was tested and did not show any significant impact on the results. The second is to use a spatial error lag (see Angeriz et al., 2006).

strongly rejects the assumption of constant group-wise variance. Likewise, the Wooldridge test rejects the assumption of no serial autocorrelation of the residuals.[8]

Model (5) estimates a new fixed-effects model with a first-order autoregressive models robust error structure, HAR(1), to tackle both issues simultaneously. The new model provided a virtually unchanged Verdoorn coefficient. The quality of the residuals showed some improvement.[9] The results of the estimation using the full panel showed widespread increasing returns in the manufacturing industry. The robustness of the estimated coefficients is shown by the high significance of the coefficients in all models used in the regressions. More importantly, the estimated results are very close to those from time-series estimations available using data from Brazil.

c) Controlling with indicator variables

The results of the estimations support Kaldor's Second Law, showing a strong connection between the rate of growth of the output and that of productivity for the Brazilian manufacturing industry. However, the full panel is composed of firms from several sectors as well as from cities belonging to different areas of the country. The next logical step is to make use of the data and create different groupings of firms according to common characteristics to test if factors such as sector and location imply distinct levels of the Verdoorn coefficient.

The new set of regressions was carried out using one and two-way fixed-effects and random-effects models including dummy variables for common characteristics. In addition, considering the results of the residuals tests from Table 1, HAR(1) models were estimated for each individual group. It is important to note that, since fixed-effects models' intercept capture part of the group-specific differences, random-effects models were used in the following regressions (Frees, 2004).

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[8] Baum (2000) stresses that this test's power is low in the contest of a panel with a large 'N' and low 'T', which is the case of the panel used. In this situation, the results of the test must be considered with caution. For more details of the Wald test, see Greene (2003). For more information on the Wooldridge test of autocorrelation, see Wooldridge (2002).

[9] The new test for serial autocorrelation only rejects the hypothesis of no serial autocorrelation at 5.4%, as opposed to the 0.01% of model (3). Ideally, the use of a second lag would be better, but the short time-span of the panel does not allow us this option. The Wald test still strongly rejects the hypothesis of homoscedasticity. However, the results showed that the test's level was reduced by one-half, without impact of its significance. Given the improvements in the regression results, the HAR(1) was accepted as preferable for the next regressions.

Three types of groupings were taken into consideration. First, firms were classified according to sectors, regardless of location. The two remaining types followed firms' participation in foreign trade, imports and exports. In this case the regressions also differentiated firms according to the region where they were located.

In the case of the trade variables, the idea is to try shed light on the determinants of the Verdoorn coefficient. Kaldor regarded Verdoorn's as essentially a dynamic relationship akin to a technical progress function, in which learning by doing plays a major role. Hence, the rationale behind of the introduction of the trade dummies is to test whether the participation of foreign trade has an impact on this function or on the rate at which learning by doing leads to productivity growth. From the point of view of exports, one can expect that firms, being subject to fiercer competition in international markets, may have higher Verdoorn coefficients. From the point of view of imports, factors such as the transference of technology may also affect positively the level of the estimated coefficients.

Sectoral regressions

The first set of regressions is for sub-sectors of the manufacturing industry.[10] The results for one and two-way fixed-effects models, random-effects and the HAR(1) random-effects model (models 1 to 4) are synthesised in Table 4 below. As expected, the comparison between models 1 to 3 show that the unit and time-specific coefficients of the fixed-effects models were associated with an important reduction in the level of the F-test for joint significance of the sectoral dummies.

Even though the F-test for joint significance for the sectoral dummies was significant for all three models, its level fell considerably from 92.0 in the random-effects model, to 3.08 in the two-way fixed-effects model. Considering model (1), the estimated coefficients of 11 out of 18 sectors were significantly different from the base dummy. On the contrary, for model (3) 11 out of 18 were *not* statistically different from the base dummy.

Model (4) shows the results of the regressions with robust autoregressive residuals carried out for each sector separately. Even though model (1) showed that

[10] The estimation of Verdoorn's Law by sub-sectors is also known as Fabricant's Law (Kennedy, 1971).

some of the sector dummies were not statistically significant from the base sector, it is clear that Verdoorn's Law holds for every sector of the manufacturing industry. The level of the returns to scale showed a significant variability, from 1.22 for Office Machinery, to 2.45 for Food and Beverages.

At this point, it is difficult to interpret the distinct sizes of the Verdoorn coefficients across sectors. An in-depth sectoral analysis would be necessary, particularly bearing in mind that most sectors were experiencing significant structural changes, implying distinct output growth rates during the period. A dataset with a longer time-span would probably offer a better base for this type of analysis. However, the gap between some of the sectors calls for closer attention. This is particularly the case when the estimated coefficients of sectors such as Electronic and IT Equipment (0.77), Automotive (0.64) and Primary Metal Industries (0.63) are compared with Food and Beverages (0.41). In this case, some insights may be found in the analysis of sectoral foreign trade patterns.

This preliminary analysis suggests that the firms' trade patterns may exert influence on the Verdoorn coefficient. We turn now to this analysis.

Table 4 – Verdoorn's Law: sectoral breakdown

		Full Panel			Sectors[1]			
	N	1-Way Random	1-Way Fixed	2-Way Fixed	1-Way Random	1-Way Fixed	2-Way Fixed	HAR(1)
Constant		0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	n.a.
q	818	0.611***	0.538***	0.522***	0.498***	0.43***	0.441***	0.408***
Textiles	336				0.076	0.070	0.0425	0.520***
Apparel and related	360				-0.003	-0.037	-0.066	0.378***
Leather and kindred	315				0.148**	0.152**	0.129*	0.551***
Wood and furniture	260				0.022	0.009	0.021	0.472***
Paper and allied	174				0.143*	0.143	0.112	0.513***
Chemicals and allied	451				0.151**	0.091	0.104	0.435***
Rubber and plastic	474				0.127**	0.100	0.053	0.503***
Stone, clay and glass	534				0.017	0.042	0.040	0.498***
Primary metal industries	184				0.242***	0.275**	0.217*	0.628***
Fabricated metal	485				0.220***	0.203***	0.156**	0.596***
Machinery	561				0.149***	0.154**	0.110*	0.530***
Office machinery	10				0.193	0.215	0.184	0.819***
Electrical machinery	190				0.151*	0.191**	0.129	0.585***
Electronic and IT	50				0.528***	0.525***	0.456***	0.765***
Precision Instruments	83				0.059	-0.001	-0.040	0.599***
Automotive	248				0.241***	0.275***	0.212**	0.641***
Other transport equipment	39				0.121	0.103	0.028	0.477***
Miscellaneous	455				0.225***	0.201***	0.173***	0.594***
Hausman		-	170.02	-	-	193.37	-	-
F-test[2]		-	-	-	92.00	4.17	3.08	-

Legend: * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

Notes: [1] The base value is the sector "Food and Beverages". HAR(1) are regressions for each individual sector.
[2] F-test for joint significance of sectoral dummies

Foreign trade: imports

The second and third types of aggregation were carried out taking into consideration each firm’s participation in foreign trade. To enable this analysis, the data from the Annual Industrial Survey was merged with trade data from the Federal Revenue and Customs Administration. In addition, in order to refine the analysis, firms were also classified according to the country’s five administrative regions: North, Northeast, Centre-West, Southeast and South. The state of São Paulo was considered independently from the remainder of the Southeast region.

For the regressions controlling for imports, two groups were created: firms that imported goods in at least one year and non-importing firms. It is important to note that the classification is based on direct trade. It is not possible to account for foreign trade transactions carried out by third party companies. Nevertheless, it is fair to say that the vast majority of the firms in the manufacturing industry import goods directly.

Table 5 shows the regressions’ results for import status and by regions. The first two columns show the results considering the full panel, including dummy variables using two-way fixed and one-way random effects. Similarly to the regressions by sector, in the fixed effects model the coefficients for importer and non-importer firms are not statistically different from each other. In the random effects model the difference, although small, is significant, at 5%. Importer firms showed returns to scale of 1.68 and non-importing firms of 1.57.

Given these results, the remaining columns show the results for HAR(1) models using dummies. The results of the regression by regions showed that for the largest regions non-importer firms showed considerably larger Verdoorn coefficients than importer firms. For the state of São Paulo, the level of the returns to scale was 1.41 and 1.87, respectively, while for the remainder of the Southeast, 1.64 and 1.84 and for the South 1.42 and 1.76, respectively. For the North and Northeast, the estimated coefficients for dummies for non-importer firms were insignificant, even though the results for importer firms showed large returns to scale. The results for both of these regions are likely to explain the inverse results found for the full panel.

Foreign trade: exports

Having seen that firms' trade status in regard to imports has a significant impact on the level of the estimated Verdoorn coefficients, the next step is to test for the impact of exporting goods. In this case, three groups were created: (i) firms which exported in all years of the sample, (ii) non-exporting firms and (iii) firms that exported occasionally. The idea is to differentiate clearly firms that have external markets as a key component of their final demand from those which only reach external markets occasionally and from those that sell all their goods in the domestic market.

The results of the regressions, which followed the same procedures as Table 8, are displayed in Table 6. For the regressions for the full panel, using both the two-way fixed effects and the one-way random-effects model showed a significant difference between exporters and non-exporters, with higher estimated Verdoorn coefficients for the latter. The coefficients for occasional exporters were not significantly different from those of the exporters.

The results for the regressions by administrative regions confirmed the pattern found for the full panel, with the difference that all three coefficients were significant. Large differences were found between exporters and non-exporters, with occasional exporters providing intermediary estimated coefficients. The smaller difference was found for firms from the state of São Paulo, with exporters, occasional exporters and non-exporters showing returns to scale of 1.39, 1.66 and 1.88 respectively. The largest difference was found for the North area, for which the respective estimated levels were 1.22, 2.24 and 2.91.

These results are, to a certain extent, counterintuitive, since exporting firms have, potentially, access to larger markets. An in-depth analysis would be necessary to establish the reason for such differences, but a tentative explanatory hypothesis may be the fact that from 1996 to 2000 exporting activities faced rather adverse effects from an overvalued exchange rate.

Table 5 – Verdoorn's Law: imports and regions

	2-Way Fixed	1-Way Random	HAR(1) Random Effects[1]				
			São Paulo	Southeast	South	Northeast	North
q (Importer)	0.511 ***	0.595 ***	0.707 ***	0.611 ***	0.702 ***	0.532 ***	0.554 ***
Non-Importer	0.029	0.041 *	-0.171 ***	-0.067 *	-0.133 ***	-0.09	0.09
Constant	0.001 ***	0.001 ***	0.000 ***	0.001 ***	0.001 ***	0.001 ***	0.001
RS Importer	1.96 ***	1.68 ***	1.41 ***	1.64 ***	1.42 ***	1.88 ***	1.81 ***
RS Non-Imp	1.85	1.57 *	1.87 ***	1.84 *	1.76 ***	2.26	1.55
N	6,027	6,027	2,794	973	1,648	382	120
F-test[2]	1.56	3.94 *	97.07 ***	4.14 *	38.96 ***	3.15	0.93

Legend: * p<0.05; ** p<0.01; *** p<0.001. RS: Returns to scale = $(1/\sigma)$.

Notes: [1]Regressions for each region individually. [2]F-test for joint significance of import dummies

Table 6 – Verdoorn's Law: exports and regions

	2-Way Fixed	1-Way Random	HAR(1) Random Effects[1]				
			São Paulo	Southeast	South	Northeast	North
q (Exporters)	0.588 ***	0.666 ***	0.718 ***	0.734 ***	0.774 ***	0.662 ***	0.823 ***
Occasional	-0.030	-0.005	-0.114 ***	-0.162 ***	-0.189 ***	-0.211 *	-0.377 ***
Non-Exporter	-0.121 ***	-0.116 ***	-0.187 ***	-0.237 ***	-0.327 ***	-0.249 ***	-0.479 ***
Constant	0.001 ***	0.001 ***	0.000 ***	0.001 ***	0.001 ***	0.001 ***	0.001
RS Exporting	1.70 ***	1.50 ***	1.39 ***	1.36 ***	1.29 ***	1.51 ***	1.22 ***
RS Occasional	1.79	1.51	1.66 ***	1.75 ***	1.71 ***	2.22 *	2.24 ***
RS Non-Exp	2.14 ***	1.82 ***	1.88 ***	2.01 ***	2.24 ***	2.42 ***	2.91 ***
N	6,027	6,027	2,794	973	1,648	382	120
F-test[2]	11.02 ***	31.8 ***	83.77 ***	51.71 ***	155.18 ***	23.26 ***	11.37 ***

Legend: * p<0.05; ** p<0.01; *** p<0.001. RS: Returns to scale = $(1/\sigma)$.

Notes: [1]Regressions for each region individually. [2]F-test for joint significance of export dummies

The regressions' results by the exports and imports groups show that foreign trade is not neutral to the level of the returns to scale, even though the prevalence of increasing returns was observed in all regressions. When the exports variable is taken into consideration, a clear-cut pattern can be noticed. Firms that exported consistently from 1996 to 2002 have shown lower levels of returns to scale than non-exporting firms. For imports, once more, firms who engage in foreign trade tended to have lower returns to scale, even though there are some significant regional variations.

These results are counterintuitive in the sense that Verdoorn's Law can be interpreted as a technological relationship in which the process of learning-by-doing plays a central role. From the point of view of exports, it would be valid to assume that firms engaged participating actively on foreign trade would be more be better prepared to react to output growth, for being subject to fiercer competition. The results did not support this view. An alternative explanation for the results may be derived from the notion that the Verdoorn coefficient reflects a learning function. In this case, exporting firms, for being more competitive, have relatively less gains from learning-by-doing than domestic firms.

It should be noted that the manufacturing industry's sectors are not distributed evenly across the country. The more dynamic sectors such as automotive, chemical, electronic, etc., tend to be concentrated in the Southeast area, whereas more traditional sectors such as food and beverages, wood and furniture and leather tend to be found in the periphery. Since there are very pronounced variations in the level of increasing returns across sectors, as seen in Table 6 above, the results found in the regressions by trade status will most certainly be influenced. Another factor, particularly for exports, concerns the scale of production and productivity levels that a firm needs to attain to be competitive in foreign markets. In this case, other characteristics such as size can be decisive.

From the regional point of view, the regressions showed that the connection between the rate of growth of the output and the rate of growth of productivity holds for every region considered. In addition, the level of the returns to scale varied markedly from region to region. These findings open another line of research. However, it is safe to argue that different Verdoorn coefficients between regions lend a certain degree of possibility to divergence in their rates of growth.

5. Concluding remarks

The results of the estimations carried out in this paper provided compelling evidence of the existence of significant increasing returns to scale in the Brazilian manufacturing industry. The regressions using different specifications, which included a proxy for the rate of growth of capital stock, revealed a Verdoorn coefficient remarkably similar to those estimated using aggregated data. The success of the estimations has important theoretical and practical implications. From a theoretical point of view, the regressions showed that, regardless of the true level at which the increasing returns to scale are generated, it is possible to successfully estimate Verdoorn's Law at the lowest level of aggregation. From a more practical point of view, the exercise showed that the manufacturing industry in Brazil is dynamic on the whole, given that firms' productivity growth showed to be highly sensitive to output growth.

It is also important to note that the regressions using the full panel were corroborated by the estimations carried out using indicator variables. The introduction of dummy variables for manufacturing industry's sub-sectors and for imports and exports also showed widespread increasing returns to scale.

The results from the panel data regressions are in line with recent estimations using time-series techniques. Nevertheless, the level of the increasing returns, particularly in the sectoral regressions, should be considered with care. It is important to bear in mind that from 1996 to 2002 the manufacturing industry was subject to a widespread restructuring process in response to ongoing process of trade and financial liberalisation, to a fierce process of internationalisation and to an overvalued currency. As a reaction to the rapidly changing environment, several sectors pursued fierce cost reducing strategies, which involved, in most cases, the reduction of the workforce. From 1997 to 2002, only in one year did the level of employment grow ahead of the output growth rate for the firms included in the panel. These events can to bias productivity gains in the period.

Another important consideration regarding the results refers to the use of a balanced panel in the regressions. When the panel was balanced, all firms who failed to survive in the market were excluded. In addition, all the firms who were acquired by other companies or merged to form a new firm in anyone year of the series were removed from the final sample. These decisions can be a potential source of bias, particularly when sectors are considered individually. Nevertheless, it is important to note that any possible bias from balancing the panel is unlikely to be large enough to completely offset the level increasing returns to scale found in the sample. Moreover, the balanced panel's representativeness is terms of output is still very significant. Hence, the balanced panel can be viewed as the core of the Brazilian manufacturing industry.

The significant Verdoorn coefficients can be taken as a indication of the dynamism of the manufacturing industry in the sense that firms are able to translate the pull of output grow into productivity gains. From the point of view of the long-run path of economic growth in general, and the country's inability to achieve higher growth rates after the 1980s in particular, the results presented suggest that the relative loss of importance of the manufacturing sector from the 1980s is a key piece of the puzzle.

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