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Abstract

This paper studies the empirical relation between market competition and innovation using Luxembourg's Structural Business Statistics. The competitive pressure in Luxembourg's markets is assessed by computing a profit elasticity measure, based on the idea of cost-efficiency. From this, the paper analyses the relation between competition and innovation performance by estimating an equation for the determinants of R&D expenditure. The results show that Luxembourg's industries are characterised by low levels of competition intensity, especially in markets relevant to competition policy and regulation. The relation between competition and innovation is non-linear and depends crucially on the efficient use of inputs to production. The impact of the distribution of technological efficiency on innovation is assessed by measuring both average technology gap and technology spread. The innovation effort is increasing as industries are closer to the frontier, and decreasing in the technology spread.

KEY WORDS: competition; innovation; profit elasticity; R&D.
JEL CODES: L10; O30;C24.

1 Introduction

This article analyses the relation between market competition and innovation in Luxembourg's non-financial industries.

The relationship between competition and innovation is relevant to both academics and policy makers. Economic and policy-oriented studies often point out the link between competitiveness and a country's economic performance and welfare. Furthermore, competitiveness and innovation are at the core of the programme of structural reform set out by EU countries in the Lisbon Strategy, with the ultimate objective of promoting economic growth and employment.

Economists, however, suggest that the relation between competition and innovation is far from being simple. The traditional view is that large market-leader firms are the driving forces

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behind innovation and technological progress (see, for example, Romer, 1990); this results in a trade-off between competition and productivity growth/innovation and has an obvious policy implication: policy makers should accept a certain degree of market power in order to encourage innovation activities. This view, however, has been questioned by several empirical studies linking higher competition to increased innovation efforts. Nickell (1994) finds that competition improves corporate performance and total factor productivity in a panel of UK firms. Griffith et al. (2006) show a positive link between competition and innovation, as measured by R&D intensity, in a panel of OECD countries. The models proposed by these authors are linear specifications, where a change in competition is measured by exogenous changes in policy variables (Griffith et al., 2006), or by a combination of exogenous indicators (Nickell, 1994). Aghion et al. (2005) abandon the linearity assumption and find evidence that the relation competition-innovation is non-linear, in the form of an inverted U-curve. (These authors measure innovation by the average number of patents in an industry.) Hagen (2009) confirms the existence of the inverted U-relationship between competition and innovation, measured by R&D intensity, in a panel of OECD countries. The inverted U-curve depicts a positive relation between competition and innovation at low levels of competition, and a decreasing one at high competition levels. Aghion et al. (2005) and Boone (2000) provide theoretical support to the non-linearity of the competition-innovation relationship. The central idea is that profits constitute the firms' main incentive to innovate. In this context, competition fosters innovation by lowering pre-innovation profits more than post-innovation rents (the so-called "escape-competition" effects). Aghion et al. (2005) argues that this effect is more likely at low-levels of competition, providing an explanation for the non-linear effect found in the data. In contrast, post-innovation profits, hence firms' incentive to innovate, are hampered by high competition.

The competition-innovation issue is of great relevance to small open economies, which are typically highly specialised (at product and industry level) and, as a result, more exposed to the international competition and economic cycle. Among small countries, Luxembourg has a very small size and a high level of GDP per capita. Its economy has a strong focus on the financial services, which account for nearly one third of its GDP. Given these facts, one would expect Luxembourg's innovation effort and competitive pressure to be quite different from those of other countries. Several international institutions, such as the OECD (Luxembourg Country Report, 2010) and the World Economic Forum (Global Competitiveness Report, 2009-2010), have highlighted weaknesses in the competitiveness of the Luxembourgish economy. The OECD notes that the lack of market competitiveness may endanger recovery and negatively affects the country's productivity. This evaluation is performed by looking at several indicators such as labour and product costs, product market regulations, barriers to new entrants and competition.

Anecdotal evidence exists on the lack of competition in Luxembourg internal markets, but little research has been done to assess the strength of competition in Luxembourgish markets adopting formal statistical criteria. To the best of our knowledge, the only study on testing perfect competition for Luxembourg industries and services is the one performed by DiMaria (2008). Empirical studies on innovation are also rare and are based on Community Innovation Survey (CIS) data. One example is Asikainen (2008), which evidence a positive link between competition, innovation, and productivity.[1] This study attempts to fill these gaps in the

[1] Czarnitzki and Bento (2010) uses CIS data to compare the impact of public funding on R&D expenditure in Luxembourg and four other countries. This study highlights the specificity of innovation policy in Luxembourg.

empirical literature using firm-level data for Luxembourg manufacturing and some key non-manufacturing sectors. Data are sourced from the Structural Business Statistics, compiled yearly by the Statec.

The empirical strategy adopted in this study is largely inspired by the work of Jan Boone and by the "2-step" empirical model of Griffith et al. (2006). It involves choices on how to measure competitive pressure and innovation effort, and comprises two steps:

1. *The computation of the competition measure.* The Boone index, obtained from the estimation of a regression of profits on costs, is preferred to traditional direct measures, such as price-cost margin and Herfindhal indices, because it is better suited to the analysis of small open economies and has better theoretical properties. Indeed, Boone (2008a) shows that the PE measure is monotonic in competition, a theoretical fact that has been found to be empirically relevant by Griffith et al. (2005). The link between market structure and competitiveness is also investigated. This is done by looking at the relation between the Boone index and the number of firms in an industry, and by checking whether industries characterised by a large number of small enterprises are more competitive than those with larger firms. (The choice of the competition measure is discussed in Section 2.)

2. *The estimation of the* ***innovation equation****, which relates innovation indicators to measures of competitiveness and several control variables.* Key variables are R&D expenditures, which proxies the innovation effort, the Boone index, and a technology gap variable that describes how efficiently, on average, firms use the production inputs within an industry. Robustness of results is assessed by using an alternative measure of competitiveness (the price-cost margin) and comparing firm- and industry-level data. R&D expenditure and patents are popular choices for measuring innovation effort in empirical studies. Here, the choice of R&D expenditure as the innovation proxy is dictated by the data available and supported by the evidence on the role of R&D in fostering innovation and technological improvements (see, for example Romer, 1990; Mairesse and Mohnen, 2002).

This empirical strategy has been implemented by several nations involved in the project "Market incentives to innovate", in the context of the OECD Working Party on Industry Analysis — OECD-WPIA. Using this methodology, Polder and Veldhuizen (2010) support the existence of the inverted U-curve in the Netherlands at both firm and industry level. The results in this paper serve as a country specific analysis linked to the above project.

The remaining of this article briefly discusses the measurement of competition (Section 2). Section 3 describes the dataset used in the analysis and discusses some issues related to industries' classification. Section 4 presents the results from the empirical analysis of competitiveness and innovation in Luxembourg's manufacturing industries. Finally, Section 5 gives concluding remarks and directions for the future research.

2 Measures of competition

To analyse the relation between competition and innovation, one has first to define what competition is and how to measure it. Neither the academic nor the policy-oriented literature, however, provide a clear and unique definition of competition. In policy-making, the term competitiveness usually refers to a broad set of conditions (costs, practises, regulatory structures, institutions, etc..) which are difficult to condensate in a single measurable indicator. Thus, the following restricts our attention to a narrower but measurable definition of competitiveness, better suited to the empirical analysis of competition by industry and to the relation of competition to key economic variables.

In the academic literature, one often encounters different views/definitions of competition. Competition is often identified with price-taking behaviour, and its implication of equality of price to marginal cost (which will be referred to as the "traditional view"). The theory of Industrial Organisation (IO) proposes instead two competing views: competition is either linked to the number of firms present in a market, or to the aggressive conduct by an incumbent firm, which affects prices and costs. Thus, an increase in competition is signalled, respectively, by an increase in the number of firms operating in the market (following a fall in entry barriers), or by the cost-price politics of operating firms.

Empirical difficulties add to theoretical ones. The Herfindhal index and market shares are empirical measures of competition inspired by the IO approach. Following instead the traditional view, researchers use the size of firms' mark-ups, or price-cost margins (PCM), to produce a direct measure of competition. The idea is very simple: a perfectly competitive market is one where firms equate prices to marginal costs. Any departure from this equality signals lack of competition and a monopolistic/oligopolistic market structure. This idea has been first proposed by Lerner, and has been applied, among others, by Hall (1988). Hall (1988) developed an indirect computation method for the PCM, by linking it to total factor productivity (TFP). This author shows that, under perfect competition, the Solow residual is given by technological change; by contrast, if the hypothesis does not hold, the residual is also a function of inputs (namely, the capital/labour ratio). In other words, under perfect competition, the technological progress is the only source of TFP growth. Several authors have pointed out empirical difficulties with Hall's method and, more generally, with PCM measures. In particular, the endogeneity induced by the correlation of inputs to TFP requires good instrumental variable, which are not always readily available (see, for example Boone et al., 2007, and references therein). More generally, a difficulty with standard mark-up measurement is the computation of costs related to the use of the capital input (ie the user cost of capital). Nonetheless, following Hall's seminal work, indirect measures of PCM have become widely popular in the empirical literature, especially when the goal is to study the relation between competition and other important economic variables (see, for example, Nickell, 1994; Aghion et al., 2005). Theoretical studies, however, have found that the the PCM provides a poor measure of competition (Boone, 2008a); empirically, the PCM has been found to be poorly correlated with alternative measures of competition (Boone et al., 2007; Duhamel and Kelly, 2009).

Here, we adopt a view of competition based on cost efficiency which has been first proposed and developed by Boone (2008b,a). The studies of Boone are important as they constitute a first attempt to disentangle the issues of cost efficiency and market power. Boone (2008b) argues that a more concentrated market does not necessarily lead to less competition. More concentrated markets can also result from a selection effect, for which inefficient firms, ie firms which cannot decreases cost when facing fiercer competition, see a fall in profit that forces them out of the market. So, this author proposes to measure the competitiveness of a market/sector using the elasticity of firms' profit with respect to marginal costs. The basic idea is that, in all markets, an increase in costs reduces profits; however, in more competitive markets, the fall in profits are higher, so firms are punished more harshly for being inefficient. As a result, profits of efficient firms increase more relatively to profit of less efficient firms, and the least efficient firms may be pushed out of the market. A possible interpretation is as follows. Let us consider what happens if firms increase the prices of their products when facing an increase in costs. If firms are price-taker (ie markets are perfectly competitive), a price increase will not be possible and the cost increase will result in a large reduction in profits. (In highly competitive markets, firms may increase the price but will loose profits due to a reduction in the quantity of goods sold.) By contrast, firms that have a degree of market power will be able to translate the cost increase into a price increase without loosing (too many) customers. In the latter case, profits will decrease less compared to the highly competitive scenario. Thus, more elastic profits signal more competitive markets.

The resulting indicator, called by the author the Profit-Elasticity (PE) index, is often referred to as the *Boone's index*. Practical implementations at industry level are based on the following empirical equation:

$$ln(P_i) = \alpha + \beta_1 ln(AVC_i) + \beta_s^{'} ln(\mathbf{X}_{is}) + \epsilon_i, \quad i \in j \tag{1}$$

where P denotes the firm's i profits, j the industry to which firm i belongs to, and $\mathbf{X}$ a vector of controls. One can see that marginal costs are approximated by average variable costs, as suggested by Hall (1988).[2] The estimated β_1 gives the PE measure for industry j. Using the model of equation 1 to measure competitive pressure in Dutch markets, Boone et al. (2007) find empirical support for the ideas that more intense competition leads to more concentrated market via the removal of inefficient firms, and that competition increases productivity.

In what follows, the Boone index is the preferred measures of the degree of competition in Luxembourg's industries. We do compare results obtained with the Boone index with those obtained using PCM for robustness; we do not consider concentration indices and market shares because these are not suited to the analysis of small open economies, as they express only domestic industrial power.

3 The Data

This study uses firms' accounting data from Luxembourg's Structural Business Statistics (SBS). The SBS is compiled each year by Statec, and provides information on firms' earnings and costs, R&D expenses, and employment. Here, we use observations on manufacturing and service industries for the year 2006. (At present we have no data on banking and insurance.) [3]

Table 1 gives summary statistics for the variables used in this analysis:

[2] Note that this amounts to assume that marginal costs are constant.

[3] In practise, the SBS survey consists of a Census of firms with at least 50 employees and a stratified sample of firms with less than 50 employees. Small firms are surveyed at most every 4 years. The eligible population is adjusted to take this rotation principle into account. Data on firms not surveyed on a particular year are then estimated/extrapolated.

Table 1: *Summary Statistics*

Variable	Mean	Std. Dev.	skewness	N
Profit	2.80	107.70	100.74	12097
Sales	4.25	112.29	96.80	12097
AVC	0.88	10.22	71.32	11862
Employment	10.34	60.91	20.85	12097
R&D expenses	1987.64	62986.77	58.16	12097

Legend: profit and sales amounts are in million Euros; average variable costs (AVC) and R&D are reported in euros; employment is measured in physical units (FTE).

One feature emerging from this summary is the small size of Luxembourgish firms: the average number of employees is about 10 workers, but the median number of workers is as low as 1. (Medians are not reported for confidentiality reasons.) On average, firms spend 1980 Euros on R&D (about 0.1% of firms' profits). Nearly 33 percent of firms report non-zero R&D expenses (amounting to 3983 enterprises); for this group of firms, R&D expenses equal on average 6000 Euros. Interestingly, firms investing in R&D have average profits and costs respectively lower and higher than firms reporting zero R&D expenses. Employment characteristics are instead comparable across the two groups of firms. (Results are not reported here for reasons of space.) In general, variables have large standard deviations, and their distributions is largely skewed. In view of their asymmetric distributions, data are transformed using the logarithmic scale.[4] For illustration, figure 1 shows the density estimate of the logarithm of profit.

The computation of the competition measures at industry level is based on the NACE industries' classification, Rev. 1.1. (Due to data availability, computations are performed at NACE 2-digit level.) To capture industries effects in the innovation equation, we further classify the industries according to their innovation content. The following section briefly discusses this innovation-based classification.

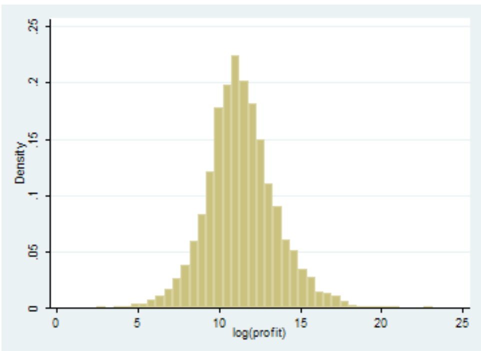

Figure 1: *Profit distribution (in logs).*

[4]Before undertaking the analysis, observations on firms with average variable costs missing (ie firms with no turnover) and zero profits have been removed from the sample. Furthermore, taking logs allows us to eliminate firms reporting zero or negative profits and/or zero employment.

3.1 A technology based classification of firms

Empirical studies of innovation often capture firms' patterns (and intensity) of innovation by using a technology-based classification of industries. In his seminal paper, Pavitt (1984) proposes a taxonomy that groups firms into four categories on the grounds of their technological competences and their main source of innovation. Categories are as follows 1) supplier dominated category; 2) specialised suppliers; 3) scale intensive; 4) science intensive. The supplier oriented category include traditional industries, which innovate mainly by acquiring machinery and equipment. So, for such firms, innovation is mainly induced by their suppliers. The second group of firms comprises specialised suppliers of machinery and equipment, where innovation is demand-dependent. Scale-intensive firms are active in mass production industries, whereas science-based firms exploit new technology knowledge, mainly sourced by in-house R&D laboratories. The supplier dominated category is the one characterised by lowest technology orientation.

In practical implementation, firms are grouped according to Pavitt's taxonomy on the basis of a NACE-type (or NAICS) 4-digit classification. The NACE classification aggregates firms into industries according to the typology of their main product; the whole industry is then attributed to one of the Pavitt's groups.

Here, we adopt the Technological Intensity classification proposed by Hatzychronoglou (1997), now adopted by the OECD and widely used by empirical application as an alternative/update to Pavitt taxonomy. This taxonomy groups *industries* into low-tech, medium-high-tech, medium-low-tech and high-tech. To adapt this classification to the case at hand, we have considered only two groups: medium/high-tech and low-tech industries. We also added a further category that comprises services, construction, and public utilities industries.

Both the classifications above present several methodological drawbacks. For example, Pavitt's taxonomy was meant to classify firms rather than industries. (Furthermore, Pavitt aimed to classify only innovative firms, rather than all firms.) Indeed, any NACE output-based classification inevitably groups firms with heterogeneous level and practices of innovation. Thus, this method leads to inaccuracies and errors in the classification of industries (this point is effectively argued by Archibugi, 2000) and may affect reliability of empirical results. This is particularly true for Luxembourg, where some high-tech firms are found in branches regarded by Pavitt's classification as low-innovation ones. More research is needed to achieve a technological intensity-based classification of Luxembourgish firms that takes into account the specificity of this economy.

4 Empirical analysis

This section presents results from the empirical analysis of the relation between competitiveness and innovation in Luxembourg's industries. Firstly, we measure the degree of market competitiveness by implementing the profit elasticity (PE) measure proposed by Boone (2008a). Then, we use the results from this analysis to specify and estimate an innovation equation. In particular, we check whether competition is capable of boosting innovation by estimating a set of equations in which innovation, as measured by R&D expenditure, is regressed on measures of markets' competitiveness, technical efficiency, employment and industry effects. Robustness of results is assessed by using an alternative measure of competitiveness and comparing firm- and industry-level data. This empirical strategy is being developed by the OECD in the context of the Working Party on Industry Analysis (WPIA).

4.1 Competitiveness in Luxembourg's industries

This section analyses two measures of competition in Luxembourgish industries: the Boone index, or profit-elasticity (PE) measure, and the price cost margin (PCM). The Boone index summarises, at industry level, the cost-efficiency of firms, whereas the PCM provides direct measures of mark-ups. The PCM is computed by dividing profit by sales, as suggested by Aghion et al. (2005).

The Boone index measures the elasticity of firms' profit with respect to their cost level. The highest the elasticity the highest is the degree of competitiveness of the industry. In practise, the index is given by the estimated β_1 coefficient (the Boone parameter) in the regression of profits on variable costs:

$$\ln(\Pi_i) = \beta_0 + \beta_1 \ln(C_i) + \beta_2 \ln(L_i) + \epsilon_i; \tag{2}$$

Here, Π_i denotes firm i's profit, C and L denote — respectively — average variable costs and employment, which is included to control for firms' size. (Variables are in logs.) Regressions are estimated separately for each industry. Table 3 summarises regression results for Luxembourg's industries. A higher value of the Boone parameter signals a higher elasticity of profits, thus a more intense competition. (Detailed regression results are reported in Table 9 in the Appendix.) The highest PE is recorded for the transport equipment manufacturing and the manufacturing of electrical equipment. These results, however, are difficult to interpret due to the low number of observations and the heterogeneity of the firms in those categories. The corresponding NACE code for motor vehicle manufacturing, for example, comprises also aerospace products. One explanation for the high efficiencies could be that these "component manufacturing" activities face stronger international competition, because they produce goods aimed at foreign markets. The lowest PEs characterise the public utilities industry (ie electricity, gas and water supply) and the wholesale industry. This findings confirm the low competition in Luxembourg's service sector pointed out by the OECD (2010). The lack of a panel of observations prevents us to check the stability of the results over time. These results, however, are in line with the previous study by DiMaria (2008). Using a different methodology, this author finds that mark ups vary greatly across industries but are on average greater for the service sectors than in manufacturing.

Table 2: *Measures of Competition: Summary statistics*

Variable	Mean	Median	St. dev.	Min	Max	Obs
Boone index	2.84	2.45	1.43	1.16	25.19	12089
PCM	.51	.40	.28	.00	.99	12089
Corr. Boone-PCM	−0.65 (0.000)					

Legend: Correlation p-value in brackets.

Table 2 gives the summary statistics for the competition measures. On average, the Boone's index equals 2.8: a 1 percent increase in costs leads to a nearly 3 percent decrease in profits. This measure is characterised by high variability: for example, in one market a one percent increase in costs leads to a 25% decrease in profits, whereas in another market the profit elasticity is as low as 1.15%.[5]

Figure 2 summarises the PEs and the PCMs found in the data with histograms. (One should note that the PCM and the Boone index are measured on different scales: the PCM varies between 0 and 1, whereas the Boone indicator is greater than 0 but can assume, at least in principle, any positive value.) If the two measures captured markets' competitive pressure correctly, one would expect a negative high correlation between them; in other words, the Boone indicator should signal low efficiencies whenever the PCM picks up high mark-ups. One can see that the correlation of the Boone index to the PCM is significant and has the right sign (negative).[6]

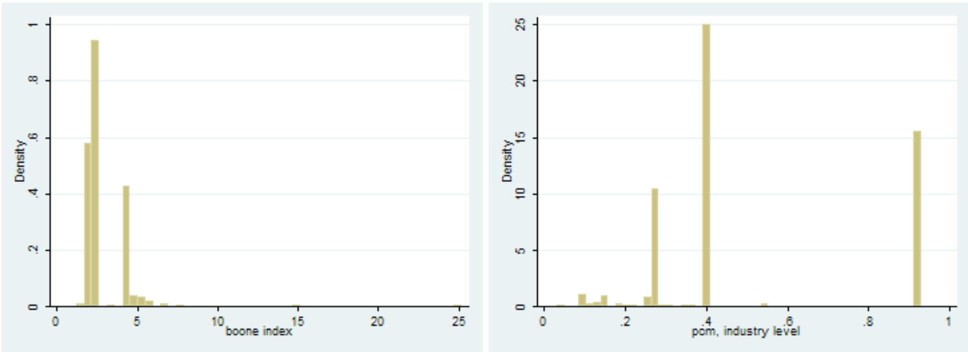

Figure 2: *Competition measures densities: Boone index (left panel) and PCM (right panel).*

Interesting features of this section's analysis of competition are as follows: 1) industries characterised by a large number of operating firms are not necessarily those with the highest PEs; 2) different measures of competition have relatively low correlation and are distributed very differently over industries. These facts prompt us to give a closer look to the link between number of firms and competition measures.

4.2 Market structure and competitiveness

An important issue, both from an academic and policy-making point of view, is the link between markets' concentration and competitiveness. Are more concentrated markets, ie markets with a low number of firms, necessarily less competitive than markets characterised by a large number of operating firms? The analysis of the previous section showed that the Boone indicator (in absolute value) does not increase with the number of firms in an industry.

[5]Boone et al. (2007) computes an average PE value of 7% for the Dutch economy, for the period 1993-2002, with variability similar to the one found in Luxembourgish data. Griffith et al. (2005) find much higher values across UK markets. Braila et al. (2010) measure generally low PEs for Belgian industries, and provide a competitiveness ranking of European countries based on the PE index which points at the UK as the most competitive economy. Care is needed, however, when comparing results for various countries, as the industries and/or the periods covered by the databases analysed may differ.

[6]The Boone index is computed at industry level, whereas the PCM is computed at firm level. So, to compute a meaningful correlation, we measure PCM at industry level by a weighted average of firms margins.

A related issue is whether industries characterised by a large number of small enterprises are more competitive than sectors characterised by larger firms.

To explore the relation between markets' concentration and competitiveness, we compute once again the Boone index for two sub-samples of firms, formed according to whether firms employ less or more than 50 workers. (This threshold value is also used by Boone et al., 2007, for a similar analysis.)[7] Tables 7 and 8 in the appendix report results for the Boone regressions run on these two datasets. The comparison of those results shows that, on average, the Boone index is lower for small firms, although its variance is also lower. (The PCM is higher.) This can also be seen in figure 3, which uses histograms to summarise the distributions of the PEs for the two groups. The center of the large firms' PE distribution is clearly shifted to the right, toward larger values of the Boone index, compared to the small firms distribution. When looking at single industries performances, in many cases the Boone indicator is higher for the large firms group. One should note, however, that comparing the two groups of firms by looking at single industries' performances presents some difficulties, as the number of observations on large firms is at times insufficient to allow regression analysis. This is because the two, small and large, types of firms are observed at different frequencies over industries. (For example, one of the heavy traditional industries, such as basic metals manufacturing, is absent from the small firms group.)

The comparison of competition measures for small and large firms to those computed for the whole population shows that the average Boone index increases considerably from 2.84 to 5.00 for the large firms, and decreases slightly for the smaller firms, down to 2.69. The ranking of industries according to the PE does not change when the whole population is restricted to the small firms group.

So, the results above suggest that there is not clear link between the intensity of competition and number of operating firms. Furthermore, large firms seem to face more intense competition than smaller firms. This contrasts with the widely-held view that SMEs increase market's competitiveness and innovation. Boone et al. (2007) have compared the competition pressure faced by small and medium enterprises (SMEs) to the one faced by large enterprises (BEs) in the Netherlands, and found similar results. These authors suggest that the fact that large firms are characterised by higher profit elasticity may be due to the type of market faced by this type of firms, as BEs compete in national markets whereas SMEs compete in local markets. This issue is relevant to the Luxembourg case, as the reference market varies widely over firms/industries. Unfortunately the SBS does not include this sort of information, but the CIS survey gives some interesting insight: Asikainen (2008, page 3) notes that "the domestic market is not the primary market for local firms. [...] The majority of the firms declare to compete in the international markets (51% in the *Grande Region*,[8] 39% within the rest of the EU countries)."

[7] Officially, in the EU, enterprises qualify as micro, small and medium-sized enterprises (SMEs) if they fulfill the criteria laid down in the Commission Recommendation 2003/361/EC. These sets a threshold for the number of employees, which must be lower than 250, and the turnover, which should be lower than 50 million euros.

[8] The *Grande Region* comprises also Rheinland-Pfalz and Saarland in Germany, Lorraine in France and Belgian Luxembourg.

Table 3: *Estimated Boone Index of competition*

Industry name	Boone	t-value	p-value	adj R^2	F stat	N
Other mining and quarrying	-4.22	-2.96	0.00	0.79	19.91	11
Food products	-5.47	-14.02	0.00	0.80	243	120
Textiles	-5.58	-7.60	0.00	0.97	210	14
Wood & wood products	-7.49	-2.39	0.06	0.92	43.82	8
Paper & printing	-4.12	-8.51	0.00	0.84	156	61
Chemicals	-2.50	-2.54	0.03	0.57	8.93	13
Rubber & plastic products	-2.33	-5.39	0.00	0.80	44.01	23
Other non-metal. mineral products	-3.14	-6.29	0.00	0.91	133	26
Basic metals	-5.66	-0.90	0.37	0.39	1.76	11
Fabricated metal products	-5.04	-12.08	0.00	0.71	158	132
Machinery & equipment n.e.c.	-5.56	-4.89	0.00	0.75	47.05	31
Machinery & electrical equipment	-14.68	-8.11	0.00	0.95	78.35	10
Medical, precision and optical instruments	-6.61	-5.23	0.00	0.74	37.40	27
Transport equipment	-25.20	-4.95	0.01	0.78	13.37	8
Furniture	-5.74	-6.33	0.00	0.61	25.69	32
Recycling	-4.49	-2.59	0.03	0.53	6.16	10
Electricity, gas & water supply	-1.21	-4.76	0.00	0.73	25.03	18
Construction	-4.42	-54.62	0.00	0.82	3085	1380
Wholesale & retail trade	-1.71	-68.80	0.00	0.85	4459	1609
Business Services	-2.46	-48.62	0.00	0.67	1731	1675

Results for regressions performed with less than 6 observations are not reported due to data confidentiality.

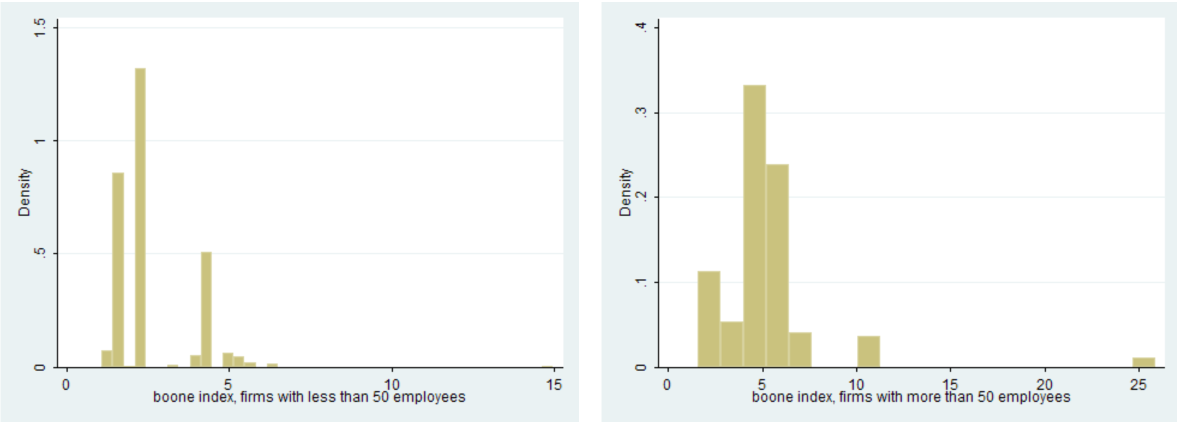

Figure 3: *Boone index distribution: (left panel) firms with less than 50 employees; (right panel) firms with more than 50 employees.*

4.3 Competition and innovation

This section presents an empirical analysis of the relation between competition and innovation in Luxembourg. The empirical model used to test this relation, largely inspired by the frameworks proposed by Aghion et al. (2005) and Griffith et al. (2006), consists of estimating the following innovation equation:

$$\ln(RD_i) = \beta_0 + \beta_1 COMP_j + \beta_2 DTF_j + \beta_3 COMP_j \times DTF_j + \beta_4 \ln(L_i) + \beta_k \sum_k D_i + \varepsilon_i; \quad (3)$$

Here, RD denotes R&D expenses and $COMP$ the measure of competition. Markets' competitive pressure is measured by the Boone index, computed in the previous section. (This choice was discussed in Section 2.) Employment (L) controls for the firms' size. DTF measures the average size of the technology gap within an industry: high levels of DTF imply that the industry is closer to the technology frontier. Thus, this variable provides a measure of heterogeneity in technical efficiency across industries.[9] The interaction term ($COMP \times DTF$) allows the marginal effect of competition on innovation to depend on the firms' distance to the frontier, introducing a non-linear term in the model. The Ds are a set of dummy variables which group firms according to the Technological Intensity (TI) taxonomy (see Section 3.1). This classification divides manufacturing industries into medium, low and high-tech industries. Here, due to limited number of observations, and the structure of Luxembourg's

[9]The technology gap variable is derived as follows. First, we compute each firm's total factor productivity (TFP), where TFP is given by the ratio of output to production inputs. (Production inputs are usually labour and capital.) The frontier is given by the firm with the highest total factor productivity (TFP) within an industry. Then, we average each firm's distance to the frontier in one industry, using the formula:

$$DTF_i j = \frac{\sum_i^n \frac{TFP_i - TFP_{Fj}}{TFP_i}}{n_j}, \quad (4)$$

where the subscript F denotes the frontier firm in industry j, and n the number of firms in industry j. Clearly, values of DTF are comprised between 0 and 1, and a low value of DTF implies that a firm is closer to the frontier. The average distance measure included in the regression is then transformed as follows: $DTF_j = 1 - DTF_{ij}$. So, higher values of DTF imply that firms are closer to the frontier.

economy, we consider three groups of industries: low-tech (base category), medium and high-tech, and services.[10] The subscript i refers to firms and the subscript j refers to industries.

Robustness of results is established by checking if different measures of competition, such as PCM, and different data-level (industry and firm-level) lead to the same conclusions.

Due to the lack of data, it was not possible to include the capital intensity ratio (K/L) and the measures of skills of the workforce, included in similar studies. So, the DTF measure should be interpreted as a measure of efficiency in the use of the labour input (that is, effectiveness of labour).

Table 4 presents results of a simple test for the linearity of the relation competition-innovation. This is done by fitting the following regression equation:

$$\ln(RD_i) = \alpha_0 + \alpha_1 COMP_j + \alpha_2 COMP_j^2 + \alpha_3 COMP_j^3 + \alpha_4 ln(L_i) + \epsilon_i; \quad (5)$$

The results suggest that the relation between competition and innovation is non-linear in this data.

To explain this non-linearity, we estimate a basic version of the innovation model of equation 3 where competition is measured, respectively, by the Boone index and the PCM, at industry and firm-level. (The latter measure allow us to test the sensitivity of results to the data levels.)[11] The TI dummies are not included at this stage. The last three columns of table 4 give the estimation results.

When measured by the Boone index (column 2), competition has a negative effect on innovation. The positive sign of the interaction term, however, shows that this effect has a switch that depends on the values of the technology gap measure. In other words, the marginal effect of competition on R&D expenses depends on the level of DTF, as follows:

$$\frac{\partial ln(RD)}{\partial COMP} = \beta_1 + \beta_3 DTF \quad (6)$$

For example, if DTF equals 0.5, the derivative of R&D with respect to COMP is positive and equal to about 0.2. The turning point is 0.35: larger DTF values imply a positive relation between competition and innovation. Thus, the positive sign of the interaction term indicates that this variable partly offset the effect of competition measures on R&D. (Similarly, the positive effect of DTF on R&D is reinforced by the intensity of competition.) This suggests that competition is good for innovation efforts when firms are close to the technological frontier. By contrast, when firms are far from the frontier, increasing competition hampers incentives to innovate. This latter case seems the most relevant to Luxembourg, as firms are characterised by low technological efficiency (one can see figure 4 in the appendix, which reports the distribution of the distances to the frontier).[12]

Thus, the negative sign for the Boone index implies that competition has a negative effect on innovation, but this is reversed as the technology gap becomes smaller and industries are more efficient. This is confirmed by the firm-level regressions (column 4). (Neither competition nor the interaction term are significant when competition is measured by the PCM at industry level.) The efficiency gap as a direct positive effect on innovation, implying

[10] One should note that the service category includes also gas, electricity and water supply and the construction industry.

[11] Industry level PCM indices are computed as weighted averages of individual PCMs, where weights are firms' market shares.

[12] These results are confirmed when using firms' level distances to technology. Results not reported here for reasons of space.

that firms spend more in R&D when they are closer to the frontier, but this effect is significant only in the firm-level regression. Furthermore, firm size appears as an important determinant of innovation expenditure.

An issue with this analysis is the fact that the distinction between the firm engaging or not engaging in R&D cannot be assumed as purely random. (In other words, the data analysed in the above regression should be regarded as a non-random sample of firms having non-zero R&D expenses.) This gives rise to a potential sample-selection bias. To tackle this problem, the innovation equations are re-estimated using a Heckman selection model. The Heckman model addresses the selection bias by modelling explicitly the decision to engage in R&D by jointly estimating a selection equation and an outcome equation. The selection equation determines whether a firm chooses to innovate or not innovate, whereas the outcome equations establishes determinants of the level of R&D expenses. Here, it is assumed that the selection mechanism is determined by firms' efficiency (that is, total factor productivity computed at firm level), firms' size and by the level of competition in the industry. (All variables are significant in determining the decision to innovate. Results are not reported but are available from the author.)

Results from the estimation of the full specification of the innovation equation are reported in table 5 and 6.

First of all, one can see that the correlation coefficients (ρ) is significantly different from zero, which supports the choice of the selection model.

The size of the firm is a significant determinant of R&D expenses across all specifications. The coefficient of the Boone index has a negative sign, with one exception (column 3), whereas the interaction term is positive, confirming the result of non-linearity in the relation between competition and innovation. The industry dummies are significant and positive for the high-tech industries. In contrast, the sign of the coefficient is negative for the dummy which identifies service industries. Service industries spend relatively less in R&D than manufacturing; manufacturing industries which are classified as medium or high-tech spend relatively more than those classified as low-tech industries.

The regression in the third column includes the square of the Boone indicator, to check for residuals non-linearities and/or omitted variables. This extra variable is significant, which leads us to re-estimate the model using a slighlty different specification (fourth column). This includes a measure of technological heterogeneity *within* industries ($DTFS$). Technological efficiency is regarded as relevant in determining innovation decisions in both theoretical and empirical studies. In particular, Aghion et al. (2005) and Boone (2000) shows that the technology *distribution* and firms' relative position in the markets affect the relation between competition and innovation. (In Aghion et al., 2005, industries can be "levelled" or "unlevelled", and in the latter case competition has a negative effect on innovation). The measure DTF, however, averages firms' distances to the industry technological frontier, so it is not capable to fully capture the technology spread within industries. This is why we introduce $DTFS$, defined as the variance of of individual DTFs within industries. This variable turns out highly significant, with a negative impact on R&D expenditure. In other words, sectors that are more heterogenous and are characterised by large gaps among firms are also characterised by lower R&D expenditure.

The impact of DTF is more difficult to assess, as the sign of its associated coefficient is not stable across specifications. Interestingly, in the specification with $DTFS$, this variable is no longer significant and retains significancy only when interacting with the competition measure.

Table 4: *Competition and innovation I: Boone index*

Dependent variable: log R&D expenses				
	Boone		PCM	PCM (firm-level)
COMP	-0.34**	-0.45***	-0.12	3.25***
	(-2.19)	(-3.07)	(-0.05)	(4.50)
$COMP^2$	0.11**			
	(2.08)			
$COMP^3$	-0.003*			
	(-1.85)			
DTF		8.94	13.44	18.95***
		(1.70)	(1.37)	(4.72)
DTF*COMP		1.27***	3.54	-19.10***
		(2.91)	(0.11)	(-3.50)
log employment	0.95***	0.90***	0.80***	0.93***
	(6.82)	(7.52))	(8.30)	(6.40)
adj R^2	0.34	0.43	0.46	0.50
F stat	122***	72.40***	86.40***	36.21***
N	1933			1243

$***$: 1% significance level$**$: 5% significance level. Robust t-ratios are in parenthesis (clustered se). RD is R&D expenses; COMP is the competition measure; DTF is average distance to technology frontier; L is employment.

To check robustness of results, we re-estimate the innovation regressions using an alternative measure of competition, the PCM, which is available at firm level. As noted above, this allows us to test the sensitivity of results to the data levels. Table 6 gives the results from the estimation of the the innovation equation with the PCM index computed at firm level (first two columns) and aggregated at industry level (last two columns).

The PCM at firm level shows a positive and significant relation with R&D expenses, suggesting once again that competition is inversely related to innovation. (Recall that higher PCM levels are associated to lower competition.) Once again, firms' size and TI dummies is positive and significant. The effect of DTF is positive and significant across specifications. The negative sign of the interaction term once again indicates that DTF offset the negative effect of competition on R&D.

In summary, in our data the relation competition-innovation has a U shape, as the negative effect of competition on innovation is partially offset by the interaction of competition and technological efficiency. This contrasts to previous studies, which found an inverted U-relationship between competition and innovation. Results, however, typically vary greatly across countries. (One can see Polder and Veldhuizen, 2010, who offer some empirical and theoretical explanations for the failure of detecting an inverted U.) .

A possible interpretation for this result is as follows. Luxembourg industries are typically heterogeneous, that is, they are characterised by the presence of large firms alongside smaller firms. If we interpret these as "unlevelled" industries, we are in the situation described by Aghion et al. (2005), where competition lowers firms' incentives to innovate. These authors argues that in "unlevelled" industries, characterised by higher spread in technology and higher distance to the frontier, increases in competition lower innovation. Indeed, in our data we found evidence that industries heterogeneity negatively affects the innovation effort; we also noted that that Luxembourg industries are typically far from the frontier.

Other noticeable results from this analysis are as follows. Firstly, the size of firms, as measured by employment, is confirmed as an important determinant of both the decision to innovate and the innovation intensity. (This result is also found in the CIS-based study by Mangiarotti, 2010; in contrast, Asikainen, 2008, finds a negative relation between R&D intensity and firms' size, which may be due to the innovation variable definition.) Second, the service sector does not innovate more than other industries and its innovation performance is comparable to low-tech industries. (This confirms results in Asikainen, 2008, where R&D is higher in financial services - not included in this analysis - but lower for business services.)

One should note that the regression results presented in this section should be interpreted with care as this analysis suffers from several limitations, such as lack of a time series dimension and difficulties in industry classification. These limitations will be addressed in future research, and are briefly discussed in the concluding remarks.

Table 5: *Competition and innovation II: Boone index*

Dependent variable: log R&D expenses				
Boone	-0.07	-0.40***	1.12***	-1.09***
	(-1.25)	(-5.35)	(3.89)	(-8.70)
Boone^2			-0.29***	
			(-5.28)	
DTF	8.20***	-12.46***	-20.13***	0.08
	(4.30)	(-4.60)	(-5.10)	(-0.03)
DTF*Boone	0.65**	1.75***	5.10***	2.86***
	(2.45)	(5.92)	(7.60)	(8.53)
DTFS				-17.85***
				(-6.75)
employment	0.85***	0.80***	0.78***	0.75***
	(19.80)	(18.85)	(18.46)	(17.85)
services		-0.85**	-1.10***	-1.23***
		(-2.33)	(-2.99)	(-3.30)
high-tech		4.18***	3.34***	3.07***
		(9.70)	(7.43)	(6.72)
LR test ($\rho = 0$)	36.07***	37.68***	44.50***	45.55***
χ^2 stat	128***	155***	193***	338***
N	7242			

5 Conclusions

This article has analysed the relation between market competition and innovation in Luxembourg's industries using business survey data. Firstly, the competitive pressure in Luxembourgish markets was assessed using the Boone index, a state-of-the-art indicator based on

Table 6: *Competition and innovation II: PCM*

Dependent variable: log R&D expenses					
PCM	2.36***	2.44***	2.29***	3.42**	
	(4.70)	(4.96)	(4.65)	(3.98)	
PCM^2			(-0.03)**		
			(-2.55)		
DTF	21.90***	7.53***	6.65**	9.55***	
	(10.91)	(2.45)	(2.64)	(3.25)	
DTF*PCM	-35.90***	-25.30***	-25.45**	-23.15***	
	(-4.95)	(-3.70)	(-3.55)	(-3.25)	
DTFS				1.15	
				(0.48)	
log employment	0.80***	0.70***	0.70***	0.67***	
	(13.45)	(11.67)	(9.20)	(11.27)	
services		-0.20	-0.55	-0.04	
		(-0.57)	(-1.62)	(-0.12)	
high-tech		3.90***	3.83***	3.80***	
		(8.10)	(7.90)		(7.78)
LR test ($\rho = 0$)	11.50***	11.40***	11.60***	11.85**	
χ^2 stat	90***	73***	155***	211***	
N	5220				

measuring the cost efficiency of firms. Then, the relation between competition and innovation was analysed using regression analysis.

Main results are as follows:

- Luxembourgish firms are generally characterised by low level of competition intensity. Low profit-cost elasticities are found for the wholesale sector and for public utilities, markets that are relevant for competition policy and regulation.

- More concentrated markets, that is, markets where the number of firms is low, are not necessarily associated with lower competitive intensity. Furthermore, industries characterised by an important presence of small firms are not more competitive than industries characterised by large firms. We suggest a possible explanation based on the different reference markets for firms;

- Competition has a significant effect on R&D expenses. The relation competition-innovation, however, is non-linear in this data, in the sense that it depends crucially on the technical efficiency of firms within an industry. In particular, we find a positive relation between competition and innovation efforts, as measured by R&D expenditures, when firms are close to the technological frontier. When firms are far away from the frontier, increases in competition can result in lower incentives to innovate. This is supported by the theory and is practically relevant in the light of the poor performance of Luxembourgish manufacturing industries in terms of efficient use of inputs.

- Innovation is a negative function of technological heterogeneity within industries.

The analysis of this article has several limitations, which suggest directions for further research. This analysis has highlighted the complex relation existing between market structure (firms number and size), competitiveness, and innovation. One of its limitation is that the NACE classification is a poor representation of what a market is. The market size and the market of reference could vary greatly from firm to firm, even within the same industry. This issue is particularly relevant for small open economies and in particular for Luxembourg. Furthermore, the lack of a time series dimension in this analysis makes difficult to deal with problems of endogeneity and reverse causality in the relation between competition and innovation. It also makes more difficult the evaluation of results, in terms of robustness of competition rankings over time. Furthermore, the analysis of the evolution of competition and its relation with innovation over time is of interest *per se*.

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Appendix: Competition measures

Table 7: *Boone Index: firms with less than 50 employees*

Industry name	Boone param.	t-value	p-value	adj R^2	F stat	N
Autres industries extractives	-4.07	-2.80	0.03	0.65	8.40	9
Industrie alimentaires	-5.29	-12.87	0.00	0.71	124.71	101
Industrie textile	-5.22	-4.24	0.00	0.88	33.38	10
Travail du bois	-9.11	-2.60	0.06	0.85	17.70	7
Industrie du papier et du carton	-3.80	-7.69	0.00	0.67	53.33	52
Industrie chimique	-3.97	-1.00	0.37	0.23	0.63	7
Industrie des plastiques	-1.96	-2.89	0.02	0.43	4.37	10
Fabrication d'autres produits min.	-3.14	-4.61	0.00	0.78	22.45	13
Travail des metaux	-4.81	-11.97	0.00	0.63	98.76	116
Fabric. machines et equipments	-4.98	-3.48	0.00	0.61	15.66	20
Fabric. instruments medicaux precision, optique	-6.20	-5.67	0.00	0.61	18.82	24
Fabrication des meubles	-5.74	-6.33	0.00	0.61	25.69	32
Recuperation	-4.29	-2.03	0.10	0.41	3.41	8
Production et dis. electricite Captage et dist. d'eau	-1.12	-4.61	0.00	0.66	61.60	14
Construction	-4.36	-52.08	0.00	0.78	2190.29	1256
Commerce de gros	-1.71	-67.84	0.00	0.83	3885.01	1564
Service aux entreprises	-2.41	-49.17	0.00	0.67	1644.63	1585
Variable/Summary stat:	Mean	Median	St. dev.	Min	Max	Obs
Boone index	2.69	2.41	1.19	1.07	14.96	13321
PCM	0.56		0.27	.00	.99	9677
Corr. Boone-PCM	-0.75					

We report results for industries with at least 6 firms.

Table 8: *Boone Index: firms with more than 50 employees*

Industry name	Boone param.	t-value	p-value	adj R^2	F stat	N
Industrie alimentaires	-6.60	-5.00	0.000	0.68	19.76	19
Industrie du papier et du carton	-4.99	-2.07	0.084	0.47	4.58	9
Industrie des plastiques	-3.71	-4.39	0.001	0.87	41.66	13
Fabric. d'autres produits min.	-3.03	-4.10	0.002	0.73	17.04	13
Metallurgie	-5.66	-0.77	0.471	0.13	0.48	9
Travail des metaux	-4.15	-1.24	0.238	0.58	11.43	16
Fabric. machines et equip.	-10.70	-4.79	0.001	0.87	33.22	11
Construction	-4.47	-15.53	0.000	0.77	204.00	124
Commerce de gros	-1.58	-11.12	0.000	0.76	70.09	45
Service aux entreprises	-5.62	-11.11	0.000	0.58	61.91	90
Variable/Summary stat:	Mean	Median	St. dev.	Min	Max	Obs
Boone index	5.00	4.47	3.00	1.58	25.89	404
PCM	.24		.25	.00	.98	379
Corr. Boone-PCM	-0.51					

We report results for industries with at least 6 firms.

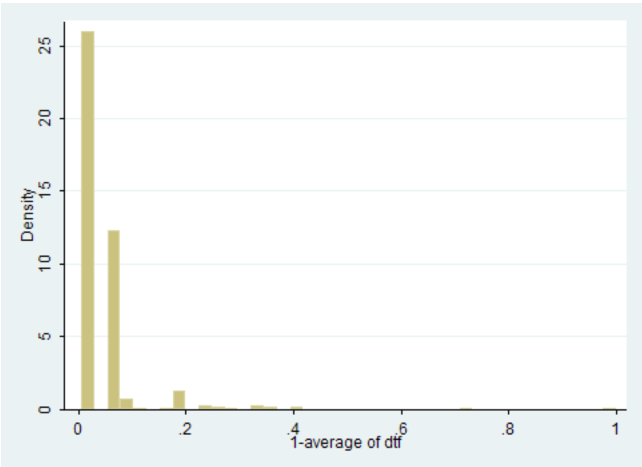

Figure 4: *Distances to the technology frontier: distribution.*

Table 9: *Estimated Boone regressions: industry*

NACE	Industry name	avc	t-value	l	t-value	adj. R^2	F stat	N
14	Autres industries extractives	-4.22	-2.96	.79	6.14	.79	19.91	11
15-16	Industrie alimentaires	-5.47	-14.02	1.02	20.56	.80	243	120
17	Industrie textile	-5.58	-6.99	1.13	19.27	.97	213	14
20	Travail du bois	-7.49	-2.39	1.20	7.45	.92	43.82	8
21-22	Industrie du papier et du carton Edition, imprimerie, reproduction	-4.12	-8.51	.95	17.65	.84	156	61
24	Industrie chimique	-2.50	-2.54	.60	2.13	.57	8.93	13
25	Industrie du caoutchouc et des plastiques	-2.33	-5.39	1.09	9.23	.79	44.01	23
26	Fabrication d'autre produits mineraux non metalliques	-3.14	-6.29	1.03	16.09	.91	133	26
27	Metallurgie	-5.66	-.90	.59	1.82	.13	1.75	11
28	Travail des metaux	-5.03	-12.08	.97	17.46	.70	158	132
29	Fabric. machines et equipements	-5.56	-4.89	.88	8.79	.75	47.05	31
31	Fabric. machines et appareils electriques	-14.68	-8.11	1.08	10.70	.94	78.35	10
33	Fabric. instruments medicaux, precision, optique, horlogerie	-6.61	-5.23	1.05	8.35	.74	37.39	27
34-35	Industrie automobile Fabric. autres materiels de transport	-25.19	-4.95	.54	2.04	.78	13.36	8
36	Fabrication des meubles	-5.74	-6.33	.87	5.65	.61	25.68	32
37	Recuperation	-4.49	-2.59	.92	3.17	.53	6.16	10
40	Produc. et dist. d'electricite, gaz et chaleur Captage, traitement et dist. d'eau	-1.21	-4.76	1.04	5.89	.73	25.03	18
45	Construction	-4.41	-54.62	.86	65.37	.82	3085	1380
51	Commerce de gros et intermediaires du commerce	-1.70	-68.80	.91	55.90	.85	4459	1609
74	Service fournis principalment aux entreprises	-2.46	-48.62	.72	44.66	.67	1731	1675

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