Competition and Innovation in Luxembourg

A Dynamic Panel Data Analysis*

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Abstract

This paper revisits the competition-innovation relationship using a panel of enterprise data stemming from various waves of the Luxembourgish innovation survey and pertaining to the period 2002-2010. Using four measures of perceived competition and three indicators of technological innovation, we estimate by full-information maximum likelihood a nonlinear dynamic simultaneous-equations model with pseudo-fixed effects and find that competition with respect to obsolete products Granger-causes innovation activities and eventually innovation success. The enterprise facing rapidly-changing technologies eventually faces the threat of seeing its products obsolete. We suggest a revision of the current policy scheme by Luxembourgish authorities regarding innovation and competition.

Keywords: O31, O32, O38, C33, C35

JEL classification: Perceived competition, technological innovation, Panel Data

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1 Introduction

This paper revisits the competition-innovation relationship using a panel of enterprise data stemming from various waves of the Luxembourgish innovation survey and pertaining to the period 2002-2010. Given the small and open economy of Luxembourg, the firms operating therein are more likely to face fierce competition especially from internationally-operating firms with possibly high innovation standards. It is therefore important for policy makers in this country to know how firms perform technologically over time when faced with competition. This has motivated the Luxembourgish government in its National Reform Program to consider innovation and competitiveness as two of its priorities. The analysis differentiates itself from other studies on that topic by using the rather new concept of *perceived* competition for which various measures exist in the innovation survey.[1] As we shall see, the competitive environment of the Luxembourgish enterprise is better described by these subjective measures than by traditional measures such as market concentration (e.g. Herfindhal index), the price-cost margin or even the newly-suggested price elasticity index of Boone (2008). To better uncover the effect of competition on innovation, we isolate the effect of past innovation behaviour which may be due to true persistence in innovation activities or intrinsic characteristics of the firm also known as individual effects.[2] Our study again stands out from existing empirical papers on the competition-innovation relation as the dynamic feature of the innovation process has largely been neglected.[3] Last but not least, we suggest a revision of the current targeting scheme by Luxembourgish policy makers when innovation or competition is being promoted.

The literature on the relation between competition and innovation dates back at least to Schumpeter (1942) who studies the link between market structure and innovation and concludes that competitive markets are not necessarily the most effective organizations to promote innovation. This view is later challenged by Arrow (1962) who finds instead that there is a greater incentive to innovate in more competitive environments. The theoretical models that result from these views predict a large range of results depending on the type of innovation (product versus process), the appropriability strategy of the innovation (patenting

[1] Luxembourg is one of the few countries, together with Germany and Canada, whose innovation survey includes measures of perceived competition.

[2] The focus here is not about distinguishing between true and spurious persistence, see Heckman (1981).

[3] The majority of empirical studies on the relation between competition and innovation are based on cross-sectional data, see for instance Peroni and Gomes Ferreira (2012) in the case of Luxembourg. Two notable exceptions are the studies by Bérubé et al. (2012) and Tingvall and Poldhal (2006) that are based on panel data. They do not, however, account for the dynamic characteristic of the innovation process.

versus licensing), and the characteristics of the firm such as its quality and its motivation towards escaping competition (see e.g. Bonanno and Haworth, 1998; Boone, 2000; and Gilbert, 2006 for a survey). Scherer (1967) predict an inverted-U relationship between competition and innovation, a view that is later popularised by Aghion et al. (2005) who show that the Arrowian effect, also referred to as the *escape-competition* effect, applies when competition is low and the Schumpeterian effect applies when competition is high. This inverted-U relation has since been put to test in a great deal of empirical studies with unambiguous results (see e.g. Tingvall and Poldhal, 2006; Peneder, 2012; Peroni and Gomes Ferreira, 2012; Polder and Veldhuizen, 2012).

One of the main issues that arises when studying the relation between competition and innovation is concerned with measuring competition. Market concentration variables, such as the Herfindhal index or 4-firm concentration ratio, and the price-cost margin (PCM) also known as the Lerner index have for a long time been the main measures of competition used in empirical studies. The shortcomings of these measures are by now widely known (see e.g. Boone, 2008; Boone et al., 2012). In our case, given the size and the degree of openness of the Luxembourgish economy, the geographic and product markets on which concentration measures of competition are based are particularly difficult to define. Market concentration measures based on Luxembourgish data are more likely to indicate an overall low level of competition in Luxembourgish industries, as shown in Peroni and Gomes Ferreira (2012), while the reality may be different especially in the knowledge-intensive service (KIS) sector. As for the PCM, its use as a measure of competition is not recommended when the time dimension is involved. Boone et al. (2012) explain that an increase of PCM over time, due to a decrease in costs, does not necessarily indicate market power but may simply reflect efficiency of the firm. If competition is intensified due to more aggressive behaviour from competitors, this will increase the PCM of efficient firms at the expense of inefficient ones. This reallocation also increases market concentration measures. Unlike the PCM and market concentration measures, the profit elasticity (PE) index proposed by Boone (2008) is shown to be able to discriminate between market power and efficiency. In other words, when the previously-mentioned reallocation is strong implying an increase in the PCM, the latter will wrongly indicate an increase in market concentration while the PE will rightly indicate an increase in (more aggressive) competition. In our case, however, the PE is also more likely to fail for the same reason as for concentration measures, i.e., the very concept of market is difficult to identify in Luxembourg.

Like Tang (2006) for Canada,[4] we use firm-specific perception of competition for many reasons. First, the above-mentioned measures are outcomes of competition and do not capture the underlying process influencing the firm decision making. Second, given a competitive environment, different firms may have different perceptions of competition, which is more likely to induce different innovative reactions to the respective perceptions. Third, the perception measures capture better the competitive environment of diversified firms that operate in various product markets. Firms in the same industry do not necessarily operate in the same market. Overseas markets are also captured by the perception measures, which may not be the case for market concentration variables, PCM or PE. Fourth, competition is multidimensional by nature, see e.g. Wright (2011), which makes its measurement by a single variable unlikely. Instead, we use four perception measures with respect to the threat of new competitors' arrival, rapidly-changing technologies, obsolete products and easy substitution of products. Thus, our perception measures reflect competition in terms of entry barriers, new processes, new products and substitutability of products. We estimate by full-information maximum likelihood a nonlinear dynamic simultaneous-equations model with pseudo-fixed effects and find that perceived competition with respect to obsolete products (or services) Granger-causes innovation activities and eventually innovation success. Furthermore, the threat of seeing the arrival of new competitors and easy substitution of products has no significant effect on innovation activities and innovation success. As for the enterprise facing rapidly-changing technologies, it eventually faces the threat of seeing its products or services obsolete. That enterprise has a higher propensity to invest in innovation and eventually becomes more successful in achieving product or process innovations. We also suggest a revision of the current policy scheme regarding innovation and competition.

The remainder of the paper is organised as follows. Section 2 presents the data and shows descriptive statistics on the main variables of interest. These descriptive statistics are reported across industries and over time. In Section 3, we explain the empirical strategy. More specifically, we motivate the specification of the model and describe the estimation method. We discuss the empirical results in Section 4 by emphasizing the role of perceived competition on innovation and by suggesting policy recommendations. Section 5 summarises the results and concludes.

[4] Perception measures adequately apply to Canada and Luxembourg for similar reasons. In other words, both countries can be considered as a small and open economy, given the size of their respective economy with respect to that of their neighbors.

2 Data

The data used in the analysis stem from four waves of the Luxembourgish CIS pertaining to all sectors covered by the survey for the periods 2002-2004, 2004-2006, 2006-2008 and 2008-2010. The data are collected at the enterprise level by CEPS/INSTEAD in collaboration with STATEC.[5] A combination of census and stratified random sampling is used where the strata are based on employment and economic activity defined by NACE Rev. 2. All enterprises with employment, in headcounts, equal to or greater than 250 or belonging to strata with less than 20 enterprises are included in the census, while those with at least 10 but less than 250 employees or belonging to strata with 20 enterprises or more are sampled. We consider enterprises with at least ten employees and positive sales at the end of each period covered by the innovation survey.

Table 1 shows the patterns of the enterprise presence in the unbalanced panel after data cleaning. Because of the dynamic structure of the model, an enterprise must be present in at least two consecutive waves to be included in the analysis. There are 480 such enterprises in our sample and roughly one third of them are present in all four waves. For each pattern, we report the mean and median employment, in headcounts, and the mean and median turnover, in millions of euros. The enterprises in the balanced panel have a significantly larger mean and median size, both in terms of employment and turnover. This is explained by the sampling scheme where enterprises that are larger than or equal to the cut-off point of 250 employees are all included in the samples and are also more likely to survive during the whole period 2002-2010 (see e.g. Agarwal and Audretsch, 2001). Using the unbalanced panel allows us to obtain more precise estimates as more observations for broader types of enterprises are used and also to control partly for survivorship biases as enterprises are allowed to enter and exit the sample at any (sub-)period.

2.1 Perceived competition and technological innovation

Tables 2 and 3 show some simple descriptive statistics, mostly means, about our main variables of interest, namely perceived competition and technological innovation.

Perceived competition

[5] CEPS/INSTEAD is a Luxembourgish public research institute and stands for *'Centre d'Études de Populations, de Pauvreté et Politiques Socio-Économiques/International Networks for Studies in Technology, Environment, Alternatives and Development'*, and STATEC is the national statistical office of Luxembourg.

Table 1: *Employment and turnover for the unbalanced panel data (sub-)samples: CIS 2004, CIS 2006, CIS 2008 and CIS 2010*

Variable							
Pattern	1111	1110	0111	1100	0110	0011	Total
# enterprises	151	28	58	78	43	122	480
% in total	32	6	12	16	9	25	100
Employment, headcounts							
Mean	358	143	113	59	46	96	211
Median	125	100	50	27	27	38	70
Turnover, millions of euros							
Mean	314	69	58	16	21	58	166
Median	24	18	9	4	4	6	13

Pattern refers to the presence/absence of firms in the four successive waves.

Four binary variables of competition are considered. They are denoted by PC 1-PC 4 and take the value one if the extent of the following characteristics describing the competition context is deemed *high* or *medium* by the enterprise:

PC 1: your position on the market is threatened by the arrival of new competitors.

PC 2: your technologies for producing goods and providing services are changing rapidly.

PC 3: your products or services are rapidly becoming obsolete.

PC 4: your products can easily be replaced by the products of your competitors.

Technological innovation

A binary variable of innovation spending directed towards technological innovation, and two binary variables of product and process innovation achievement are considered. Innovation spending includes in-house and extramural R&D, acquisition of machinery and equipment, acquisition of computer hardware and software, and acquisition of external knowledge such as patents, non-patented inventions and knowhow. This variable takes the value one if the enterprise reports positive figures on either spending at the end of each period covered by the innovation survey. Product innovation refers to goods or services that are new (to the enterprise, not necessarily to the market) or significantly improved, and process innovation refers to new or significantly improved production methods, logistics, delivery and distribution methods, and supporting activities such as maintenance systems.

Descriptive statistics

Table 2 reports descriptive statistics on perceived competition and technological innovation for various industries, categories of industries and the whole sample.[6] The figures

[6] All sectors of the Luxembourgish economy covered by the CIS are analysed. Because of insufficient number of observations, the following sectors have been removed from the analysis, namely mining and

Table 2: Perceived competition, innovation input and innovation output by industry

NACE	Industry	# obsv.	Perceived competition				Innovation		
			PC 1	PC 2	PC 3	PC 4	Spending	Product	Process
Manufacturing		524	0.64	0.67	0.41	0.78	0.58	0.48	0.42
Low-tech		354	0.65	0.63	0.38	0.76	0.47	0.39	0.39
10-12	Food, drinks & tobacco	83	0.65	0.60	0.34	0.75	0.29	0.27	0.29
13	Textile	17	0.53	0.59	0.29	0.82	0.71	0.53	0.59
16-18	Wood, paper	37	0.62	0.73	0.38	0.78	0.57	0.35	0.51
22	Plastics	42	0.71	0.69	0.45	0.79	0.74	0.71	0.64
23	Non-metals	38	0.68	0.63	0.37	0.74	0.63	0.55	0.45
24, 25	Metals	104	0.63	0.58	0.35	0.72	0.37	0.30	0.30
31-33	NEC	33	0.67	0.70	0.58	0.82	0.48	0.39	0.30
High-tech		170	0.63	0.74	0.48	0.82	0.82	0.66	0.49
20	Chemicals	35	0.51	0.63	0.54	0.83	0.91	0.63	0.51
26	Electronics	16	0.63	0.63	0.44	0.81	0.94	0.94	0.63
27	Electrical	28	0.64	0.79	0.43	0.82	0.57	0.39	0.32
28	Machinery	63	0.68	0.81	0.54	0.84	0.92	0.79	0.49
29, 30	Vehicles	28	0.64	0.75	0.36	0.75	0.64	0.54	0.57
Services		754	0.59	0.66	0.49	0.72	0.50	0.46	0.40
LKIS‡		276	0.67	0.61	0.43	0.71	0.32	0.28	0.29
46	Wholesale	141	0.68	0.65	0.50	0.73	0.35	0.37	0.35
49	Transport, land	114	0.65	0.60	0.37	0.71	0.28	0.19	0.22
52, 53	Storage	21	0.67	0.48	0.33	0.57	0.29	0.10	0.24
KIS‡		478	0.55	0.69	0.53	0.72	0.61	0.57	0.46
50, 51	Air & water transport	28	0.43	0.36	0.29	0.57	0.43	0.25	0.43
58-63	ICT	190	0.65	0.76	0.60	0.74	0.57	0.58	0.36
64-66	Finance	173	0.45	0.71	0.56	0.73	0.71	0.67	0.65
71	Engineering	87	0.56	0.63	0.37	0.72	0.56	0.43	0.32
Utilities		70	0.43	0.54	0.21	0.63	0.37	0.26	0.26
35	Elec. & gas	31	0.45	0.48	0.19	0.55	0.35	0.19	0.19
36-38	Water supply	39	0.41	0.59	0.23	0.69	0.38	0.31	0.31
Whole sample		1348	0.60	0.66	0.45	0.74	0.53	0.46	0.40

‡KIS and LKIS mean respectively knowledge-intensive and less knowledge-intensive services.

represent percentages of enterprises that deem the previously-listed characteristics describing the competition context high or medium, and percentages of enterprises that undertake innovation activities and achieve successfully product or process innovations.[7] We observe the following patterns. Firstly, competition is deemed lower overall in the utilities sector

quarrying (NACE 05-09), construction (NACE 41-43), real estate activities (NACE 68), legal and accounting activities (NACE 69), activities of head offices and consultancy (NACE 70), other professional, scientific and technical activities (NACE 74), rental and leasing activities (NACE 77), travel agency, tour operator reservation service and related activities (NACE 79), human health activities (NACE 86), and repair of computers and personal and household goods (NACE 95).

[7] We make a distinction between an innovative enterprise and an innovator. The former refers to enterprises that undertake innovative activities regardless of whether they are successful or not. The latter refers to enterprises that manage to achieve successfully product or process innovations.

Table 3: Perceived competition, innovation input and innovation output by CIS

CIS	# enterprises	%	Perceived competition				Innovation		
			PC 1	PC 2	PC 3	PC 4	Spending	Product	Process
2002-2004	257	19	0.62	0.54	0.42	0.75	0.61	0.47	0.44
2004-2006	358	27	0.65	0.59	0.66	0.46	0.54	0.49	0.36
2006-2008	402	30	0.60	0.51	0.40	0.75	0.48	0.42	0.45
2008-2010	331	24	0.54	1.00	0.30	1.00	0.50	0.46	0.36

than in the manufacturing and the service sector. These statistics on subjective competition reflect the actual competition in these sectors which are known to be almost monopolistic in Luxembourg.[8] Similarly, the percentage of innovative enterprises and that of innovators are lower in the utilities sector. Secondly, the arrival of new competitors (PC 1) constitutes less of a threat to incumbents in high-technology manufacturing and knowledge-intensive services than in low-technology manufacturing and less knowledge-intensive services. The enterprise perception of competition with respect to that component also confirms the observed fact that entry costs are generally higher in high-technology and knowledge-intensive sectors than in low-technology and less knowledge-intensive sectors. However, the perception of competition with respect to rapidly-changing technologies (PC 2), products or services that become obsolete rapidly (PC 3), and products that can be easily replaced by competitor's products (PC 4) is higher in high-technology and knowledge-intensive sectors than in low-technology and less knowledge-intensive sectors, which is also to be expected. Last but not least, the percentage of innovative enterprises is higher in high-technology and knowledge-intensive sectors than in low-technology and less-knowledge intensive sectors. Furthermore, since innovation input (e.g. R&D) is closely related to innovation output (e.g. new product), we also observe higher percentages of innovators in the former sectors than in the latter.

Table 3 shows similar descriptive statistics on perceived competition and technological innovation by CIS for enterprises that are present in at least two consecutive waves (see Table 1). The enterprise perception of competition does not exhibit an unambiguous pattern over time. It has decreased between 2002 and 2010 when competition is about the arrival of new competitors (PC 1) and outdated products or services (PC 3), and increased when competition is about rapidly-changing technologies (PC 2) and easy substitution of products (PC 4). Both the decrease and the increase are non-monotonic. As for technological innovation, we observe a non-monotonic decrease in the percentage of innovative enterprises

[8]Market concentration is very high in the electricity and gas sector. In 2010, for instance, the dominant player in the retail market for electricity, Enovos, had a market share of 85% and the three largest electricity distribution companies controlled 94% of the market. Furthermore, supplier switching rate was very low, no more than 0.2%, one of the lowest in the EU27.

and innovators between 2002 and 2010.

2.2 Relation between perceived competition and technological innovation

Table 4 shows tetrachoric correlations between perceived competition taken at period $t-1$, and innovation output taken at period t. As we shall see in the next section, perceived competition is considered as *predetermined* so as to avoid any simultaneity between competition and innovation (see e.g. Futia, 1980). The various components of competition are positively and significantly correlated, which reflects its multidimensional nature (see e.g. Wright, 2011). The largest observed correlation is between high or medium perception of competition with respect to rapidly-changing technologies (PC 2) and outdated products or services (PC 3). Innovation is observed to be positively and significantly related to competition only when the latter is about rapidly-changing technologies and outdated products or services. Innovation spending and the achievement of product or process innovations are positively and significantly correlated.

Table 4: Tetrachoric correlation between perceived competition in period t-1 and technological innovation in period t

	Perceived competition$_{t-1}$				Innovation$_t$		
	PC 1	PC 2	PC 3	PC 4	Spending	Product	Process
Perceived competition$_{t-1}$							
PC 1	1						
PC 2	0.17**	1					
PC 3	0.18**	0.73**	1				
PC 4	0.33**	0.18**	0.10†	1			
Innovation$_t$							
Spending	0.05	0.28**	0.30**	0.08	1		
Product	0.04	0.22**	0.22**	0.14*	0.874**	1	
Process	0.04	0.19**	0.22**	0.06	0.802**	0.604**	1

Significance levels : $\dagger$: 10% $*$: 5% $**$: 1%

In the competition-innovation relationship, we control for the conglomerate status of the enterprise,[9] its size, the university degree of its employees and whether or not it receives financial support from local or national government or from the European Union. These explanatory variables are all binary with the exception of size, captured by employment in headcounts, which is continuous. Descriptive statistics on these variables indicate that the majority of enterprises of our sample are either independent enterprises or multinationals.

[9] Independent enterprises are defined as those who do not belong to any conglomerate. Local conglomerate and multinational enterprises are those for which the conglomerate's head office is located respectively in Luxembourg and abroad.

Table 5: Descriptive statistics on size, university degree of employees, conglomerate status and subsidies

Variable	Mean	Median	Std. Dev.	Min.	Max.
Conglomerate status					
Independent	0.417	-	-	0	1
Local conglomerate	0.222	-	-	0	1
Multinational	0.361	-	-	0	1
Employment, headcounts	211	70	509	10	6491
Univ. degree of emp.					
<5%	0.253	-	-	0	1
[5%, 50%]	0.465	-	-	0	1
>50%	0.282	-	-	0	1
Subsidies	0.180	-	-	0	1

They have on average 211 employees, and half of them have less than or exactly 70 employees. For a quarter of them, the percentage of staff with a university degree is less than 5%, for almost half of them this percentage lies between 5% and 50%, and for 28% of them this percentage is greater than 50%. Finally, 18% receive financial support from local or national government or from the European Union. The inclusion of these explanatory variables in the model is motivated in detail in the next section.

3 Empirical strategy

To answer our research question, we consider the following nonlinear dynamic simultaneous-equations model

$$spend_{it} = \mathbb{1}[\gamma_1 spend_{i,t-1} + \boldsymbol{\beta}'\mathbf{compet}_{i,t-1} + \boldsymbol{\delta}_1'\mathbf{x}_{it} + \epsilon_{1it} > 0], \tag{3.1}$$

$$prod_{it} = \mathbb{1}[\gamma_2 prod_{i,t-1} + \vartheta spend_{it} + \boldsymbol{\delta}_2'\mathbf{z}_{it} + \epsilon_{2it} > 0], \tag{3.2}$$

$$proc_{it} = \mathbb{1}[\gamma_3 proc_{i,t-1} + \lambda spend_{it} + \boldsymbol{\delta}_3'\mathbf{z}_{it} + \epsilon_{3it} > 0], \tag{3.3}$$

where $\mathbb{1}$ denotes the indicator function which takes the value one if its argument is positive, and zero otherwise.

Equation (3.1) explains enterprise i's decision to engage in innovation activities at period t,[10] which depends upon some latent innovation incentive that can be expressed as a function of past innovation spending, $spend_{i,t-1}$, perceived competition in the previous period, $\mathbf{compet}_{i,t-1}$, observed enterprise and industry characteristics, $\mathbf{x}_{it}$, and other unobserved

[10] According to our notations, t corresponds to the periods 2002-2004, 2004-2006, 2006-2008 and 2008-2010. Since we use a first-order autoregressive model with an unbalanced panel, the minimum and maximum number of time periods equals respectively 2 and 4, see Table 1.

factors summarised in the error, ϵ_{1it}. If the incentive is positive, the enterprise is observed to carry out innovation activities, in which case $spend_{it}$ is equal to one, otherwise it is equal to zero. The coefficients to be estimated are γ_1 which captures persistence in innovation spending, and $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$ which capture respectively the effect of perceived competition and other observed enterprise and industry characteristics on innovation spending.

Equations (3.2) and (3.3) explain respectively product and process innovation. The ability to achieve these innovations is unobserved but defined as a function of past product and process innovation, respectively $prod_{i,t-1}$ and $proc_{i,t-1}$, innovation spending, $spend_{it}$, observed enterprise and industry characteristics, $\mathbf{z}_{it}$,[11] and other unobserved factors, ϵ_{2it} and ϵ_{3it}. The reasoning underlying the link between the unobserved ability to achieve product or process innovation and the actual achievement of these innovations is similar to that of equation (3.1). In equation (3.2), γ_2 captures the persistence of product innovation, and ϑ and $\boldsymbol{\delta}_2$ the effect of innovation spending and other observed enterprise and industry characteristics on product innovation. The coefficients of equation (3.3), γ_3, λ and $\boldsymbol{\delta}_3$, are interpreted similarly.

3.1 Model specification

Besides the four measures of competition that enter equation (3.1), we explain the probability of innovation spending and innovation success in period t by lagged counterparts to capture persistence, which is an inherent characteristic of the innovation process (see e.g. Geroski et al., 1997; Cefis and Orsenigo, 2001). Persistence in innovation spending can be explained by the existence of "sunk costs" (see e.g. Máñez et al., 2009). In other words, resources that are spent, for instance, on scientists to carry out R&D cannot be recovered. As a result, carrying out innovation activities is likely to be time dependent. Persistence in innovation success can be observed for several reasons. First, because of information asymmetry, firms may be more willing to rely on retained earnings rather than to seek external funding for their future innovations (Bhattacharya and Ritter, 1983). Second, Mansfield's (1968) "success breeds success" postulates that innovation success confers advantages in technological opportunities that make further success more likely. Third, according to the evolutionary theory (see e.g. Nelson and Winter, 1982), radical innovations are often followed by a succession of incremental innovations along a technological trajectory. Furthermore,

[11] The observed enterprise and industry characteristics, $\mathbf{z}_{it}$, explaining product and process innovation are assumed to be the same.

in a process similar to Arrow's learning-by-doing, firms learn by innovating and develop organisational competencies along that trajectory (see e.g. Dosi and Marengo, 1994).

The vectors of explanatory variables, $\mathbf{x}_{it}$ and $\mathbf{z}_{it}$, include as common components two binary variables for local conglomerate and multinational enterprise, and employment in headcounts. The latter variable is log-transformed in the estimation. Firms that are part of a conglomerate are expected to be more innovative as they benefit from knowledge spillovers, internal access to finance, and synergies in marketing (Veugelers and Cassiman, 2004). According to Schumpeter (1942), firm size is expected to affect positively innovation behaviour as larger corporations have more and better resources to invest and wield more monopolistic power that enables them to capture the benefits of their innovation output. Two additional explanatory variables that are not in $\mathbf{z}_{it}$, namely university degree of employees and public financial support, are also included in $\mathbf{x}_{it}$. Human capital or research capacity, proxied by university degree of employees, is an indicator of firms' ability to deploy innovative efforts. It can therefore be argued that skilled employees will more likely constitute the R&D personnel and hence play an important role in the firm's innovation efforts. Two binary variables for enterprises with percentage of employees with university degree between 5% and 50%, and greater than 50% are included in the estimation.[12] As for public financial support, we expect enterprises that receive subsidies for innovation to be more innovative, although evidence on this score is mixed (David et al., 2000). In order to uncover a causal effect of subsidies on innovation activities and avoid potential endogeneity of subsidies (see e.g. Wallsten, 2000), we include in equation (3.1) a lagged dummy variable for enterprises that receive public financial support. Finally, equations (3.2) and (3.3) can be seen as knowledge production functions where the main input to innovation output is innovation spending.

3.2 Estimation

Since we consider a panel data framework, individual and time effects must be accounted for.[13] Hence, the error terms of equations (3.1)-(3.3) are written as

$$\epsilon_{lit} = \alpha_{li} + \mu_{lt} + \nu_{lit}, \qquad l \in \{1, 2, 3\}, \tag{3.4}$$

[12] The <5% modality is used as the reference category, see Table 5.

[13] Tables 2 and 3 particularly show large industry and time heterogeneity in innovation and perceived competition.

where α_{li} and μ_{lt} are respectively individual and time effects, and ν_{lit} denotes the idiosyncratic errors. Equation (3.4) is referred to as two-way error components disturbances in the econometric literature (Baltagi, 2008). We consider a pseudo fixed-effects approach with time dummies, which consists in writing α_{li} as

$$\alpha_{li} \simeq \sum_{j=1}^{J} \alpha_{lj} d_{ij} \tag{3.5}$$

where j denotes the industry to which the enterprise belongs, J is the total number of industries,[14] and d_{ij} denotes binary variables defined as

$$d_{ij} = \begin{cases} 1 & \text{if } i \in j \\ 0 & \text{if } i \notin j \end{cases} .$$

The pseudo fixed-effects approach has various appealing features in the context of our data. First, given the size of Luxembourg, many industries consist of very few firms so that the extent of heterogeneity within industries is limited, albeit large across industries. Furthermore, some industries are known to be quasi-monopolistic where a dominant player and its subsidiaries control the market.[15] Heterogeneity is more likely to be limited within these industries as well. Second, this approach avoids the incidental parameters problem (see Neyman and Scott, 1948) since the number of intercept parameters to be estimated, α_{lj}, does not increase with i. As a result, the presence of individual effects in equations (3.1)-(3.3) does not bring additional difficulty to the estimation procedure.

The model is estimated using full information maximum likelihood (FIML). In other words, equations (3.1)-(3.3) are jointly estimated by maximum likelihood, which requires distributional assumptions regarding the error terms $\boldsymbol{\nu}$. Given the regressors and the pseudo-fixed effects, the error terms are assumed to be normally distributed with mean $\mathbf{0}$ and covariance matrix $\boldsymbol{\Sigma} = \begin{pmatrix} 1 & & \\ \rho_{12} & 1 & \\ \rho_{13} & \rho_{23} & 1 \end{pmatrix}$, where ρ_{12}, ρ_{13} and ρ_{23} are also to be estimated. The log-likelihood consists of $2^3 = 8$ components calculated over various subsamples defined by equations (3.1)-(3.3), i.e.,

$$\ln L = \sum\nolimits_{000} \ln L_{000} + ... + \sum\nolimits_{111} \ln L_{111}, \tag{3.6}$$

[14] In the estimation, we include 2-digit industry dummies defined according to NACE Rev. 2.

[15] This is the case of Enovos, for instance, in the electricity and gas sector.

where $\ln L_{mnp}$, $(m, n, p \in \{0, 1\})$, denotes the individual contributions to the log-likelihood and $\sum_{mnp}$ defines the observations of the various subsamples. The individual likelihoods for which $p = 0$ are calculated as

$$L_{mn0} = \int_a^b \int_c^d \int_{-\infty}^{-A_{3it}} \phi_3(\nu_{1it}, \nu_{2it}, \nu_{3it}) d\nu_{1it} d\nu_{2it} d\nu_{3it}, \tag{3.7}$$

where ϕ_3 denotes the density function of the trivariate standard normal distribution, the integral bounds a, b, c, and d are defined as

$$(a, b) = \begin{cases} (-\infty, -A_{1it}) & \text{if } j = 0 \\ (-A_{1it}, \infty) & \text{if } j = 1 \end{cases}$$

$$(c, d) = \begin{cases} (-\infty, -A_{2it}) & \text{if } k = 0 \\ (-A_{2it}, \infty) & \text{if } k = 1 \end{cases}$$

and A_{1it}, A_{2it} and A_{3it} are defined respectively as

$$A_{1it} \equiv \gamma_1 spend_{i,t-1} + \boldsymbol{\beta}' \mathbf{compet}_{i,t-1} + \boldsymbol{\delta}_1' \mathbf{x}_{it} + \alpha_{1j} d_{ij}, \tag{3.8a}$$

$$A_{2it} \equiv \gamma_2 prod_{i,t-1} + \vartheta spend_{it} + \boldsymbol{\delta}_2' \mathbf{z}_{it} + \alpha_{2j} d_{ij}, \tag{3.8b}$$

$$A_{3it} \equiv \gamma_3 proc_{i,t-1} + \lambda spend_{it} + \boldsymbol{\delta}_3' \mathbf{z}_{it} + \alpha_{3j} d_{ij}. \tag{3.8c}$$

Similarly, the individual likelihoods for which $p = 1$ are calculated as

$$L_{mn1} = \int_a^b \int_c^d \int_{-A_{3it}}^{\infty} \phi_3(\epsilon_{1it}, \epsilon_{2it}, \epsilon_{3it}) d\epsilon_{1it} d\epsilon_{2it} d\epsilon_{3it}. \tag{3.9}$$

The multiple integrals of equations (3.7) and (3.9) involve multivariate cumulative distribution functions which are evaluated using the Geweke-Hajivassiliou-Keane simulator so that the resulting log-likelihood to be maximised is a simulated log-likelihood.

Since the model has nonlinear conditional means, the coefficients of equations (3.1)-(3.3) only pick up the sign and significance of the effects of the explanatory variables. To quantify them, we need to calculate average partial effects. Because of the simultaneous-equations characteristic of the model, three types of average partial effects (APEs), namely *direct*, *indirect* and *total*, can be computed. For instance, competition is assumed to have a direct effect (captured by $\boldsymbol{\beta}$) on innovation spending, as is usually the case in theoretical and applied studies (see e.g. Gilbert, 2006; Levin et al., 1985), and only an indirect effect on innovation success unlike Tang (2006).[16] The indirect effect operates through the effect of innovation spending on innovation success captured by ϑ or λ. The total effect of any explanatory variable common to all three equations on innovation success is the sum of the direct effect of that variable on innovation success, captured by $\boldsymbol{\delta}_2$ or $\boldsymbol{\delta}_3$, and the indirect effect transmitted to innovation success via the effect of innovation spending on innovation success.[17] The expressions of the the APEs are given in Habiyaremye and Raymond (2013).

4 Empirical results

Tables 6 and 7 show estimates of APEs for a static and a dynamic specification of the competition-innovation relationship. On the basis of likelihood ratio tests, the preferred specification consists of first-order autoregressions with pseudo fixed-effects. In other words, innovation spending and innovation success are time dependent and exhibit industry heterogeneity. *Ceteris paribus,* the probability to spend in innovation in period t given that one has spent in innovation in period $t-1$ increases by 0.262. Similarly, the probability of past product innovators to achieve product innovations increases by 0.106, and that of past process innovators to achieve process innovations also increases, albeit to a lesser extent. These results are in accordance with existing empirical results on persistence in innovation spending (Peters, 2009) and in product or process innovation (Flaig and Stadler, 1994).

Larger enterprises and those with a better skilled labour force have a larger probability to invest in innovation and to be technologically successful. Local conglomerate enterprises are more likely to spend in innovation and to successfully introduce product innovations than independent firms and multinational enterprises (MNEs). Since MNEs and local conglomerate enterprises are equally likely to introduce process innovations, it may well be the case that foreign subsidiaries of MNEs are in charge of undertaking innovation activities and developing new products elsewhere, where it is more advantageous to do so. This result about innovation activities and innovation success of MNEs may seem surprising given the attractiveness of Luxembourg to welcome R&D workforce.[18] However, as pointed out by

[16] In Tang's (2006) study, the 'knowledge production function' relating innovation output to competition does not control for innovation input. As a result, any seemingly significant direct effect of competition on innovation output may actually be an indirect effect via the effect of innovation input on innovation output. In our study, there is no evidence of a direct effect of competition on innovation output.

[17] In the case at hand, the total effect of competition on innovation success is simply the indirect effect, since competition does not enter equations (3.2) and (3.3).

[18] The number of R&D workers per 1000 workers in Luxembourg is above the EU28 average. For instance,

Meyer-Krahmer and Reger (1999), the attractiveness of a country to welcome R&D units is not so much determined by factors such as costs and wages but rather by "dynamic efficiency". In other words, the factors driving R&D location decisions have more to do with the value-added effects of transnational learning processes along the whole value-added chain, i.e. from R&D to product sales and services. Furthermore, it has been observed that Luxembourg is not at all on track to reach its R&D intensity target for 2020 of 2.3%-2.6% of GDP because its R&D intensity exhibits a declining trend which is due to the sharp decrease in business R&D intensity as opposed to the modest increase in public R&D intensity.[19] Finally, the results show that once past innovation behaviour and industry heterogeneity are accounted for, the effect of subsidies becomes insignificant. In other words, receiving subsidies does not Granger-cause innovation activities and innovation success.

4.1 The role of perceived competition

A high or medium perception of competition with respect to arrival of new competitors (PC 1), rapidly-changing technologies (PC 2) and easy substitution of products (PC 4) has no significant effect on innovation activities and innovation success. When competition is about outdated products or services (PC 3), a high or medium perception Granger-causes innovation activities and eventually innovation success. In other words, an enterprise that perceives that its products or services are outperformed by those of its competitors has a larger probability to increase its innovation activities, which eventually translates into a larger probability to achieve product or process innovations. When PC 3 is not included in the specification, competition about rapidly-changing technologies Granger-causes innovation activities and innovation success. PC 2 and PC 3 have the largest correlation among the competition variables (see Table 4) so that the effect of PC 2 is taken over by that of PC 3 when both are included. The threat for the enterprise to see rapidly-changing technologies is eventually translated into the threat of seeing its products or services obsolete.

The effect of high or medium perception of competition about outdated products or services on innovation spending and innovation success decreases with firm size (see Figure 1). In other words, upon perceiving high or medium competition about obsolete products

Goodyear's Luxembourg research center is the second most important in the world after that of the US. This is reflected in Table 2 where the rubber & plastics industry is observed to be more innovative and more successful than not only the low-technology sector but also the manufacturing sector as a whole.

[19]Between 2000 and 2011, business R&D intensity decreased from 1.53% to 0.98% of GDP while public R&D intensity increased from 0.12% to 0.45% of GDP.

Table 6: FIML estimates of the relation between perceived competition and technological innovation: Static model

Variable	APE	Std. Err.	APE	Std. Err.
	no pseudo fixed-effects		with pseudo fixed-effects	
		Innovation spending		
Perceived competition$_{t\text{-}1}$				
PC 1	-0.002	0.032	0.013	0.031
PC 2	$0.065^{\dagger}$	0.036	0.049	0.034
PC 3	0.097^{**}	0.037	0.099^{**}	0.036
PC 4	0.011	0.034	-0.008	0.032
Local conglomerate	0.122^{**}	0.041	0.102^{*}	0.040
Multinational enterprise	0.015	0.037	-0.033	0.038
Employment (in log)	0.076^{**}	0.013	0.093^{**}	0.013
Univ. degree of emp.				
[5%, 50%]	0.649^{**}	0.121	0.149^{**}	0.040
>50%	0.797^{**}	0.136	0.243^{**}	0.054
Subsidies$_{t\text{-}1}$	0.230^{**}	0.041	0.162^{**}	0.043
		Product innovation		
Innovation spending	0.734^{**}	0.034	0.693^{**}	0.042
Perceived competition$_{t\text{-}1}$				
PC 1	-0.001	0.023	0.001	0.022
PC 2	$0.048^{\dagger}$	0.026	0.034	0.024
PC 3	0.071^{*}	0.027	0.069^{**}	0.025
PC 4	0.008	0.025	-0.006	0.022
Local conglomerate	0.128^{**}	0.041	0.106^{**}	0.041
Multinational enterprise	0.058	0.036	0.001	0.038
Employment (in log)	0.094^{**}	0.012	0.108^{**}	0.013
Univ. degree of emp.				
[5%, 50%]	0.159^{**}	0.030	0.104^{**}	0.028
>50%	0.195^{**}	0.034	0.170^{**}	0.039
Subsidies$_{t\text{-}1}$	0.168^{**}	0.031	0.113^{**}	0.031
		Process innovation		
Innovation spending	0.599^{**}	0.042	0.634^{**}	0.039
Perceived competition$_{t\text{-}1}$				
PC 1	-0.001	0.019	0.001	0.020
PC 2	$0.039^{\dagger}$	0.022	0.031	0.022
PC 3	0.058^{*}	0.023	0.063^{**}	0.023
PC 4	0.006	0.020	-0.005	0.020
Local conglomerate	$0.080^{\dagger}$	0.042	0.106^{*}	0.042
Multinational enterprise	0.112^{**}	0.037	0.087^{*}	0.040
Employment (in log)	0.097^{**}	0.012	0.097^{**}	0.013
Univ. degree of emp.				
[5%, 50%]	0.130^{**}	0.025	0.094^{**}	0.026
>50%	0.159^{**}	0.029	0.155^{**}	0.036
Subsidies$_{t\text{-}1}$	0.137^{**}	0.026	0.103^{**}	0.028
Industry dummies	no		yes	
Time dummies	yes		yes	
Log-likelihood	-1252.325		-1171.724	
# observations		868		

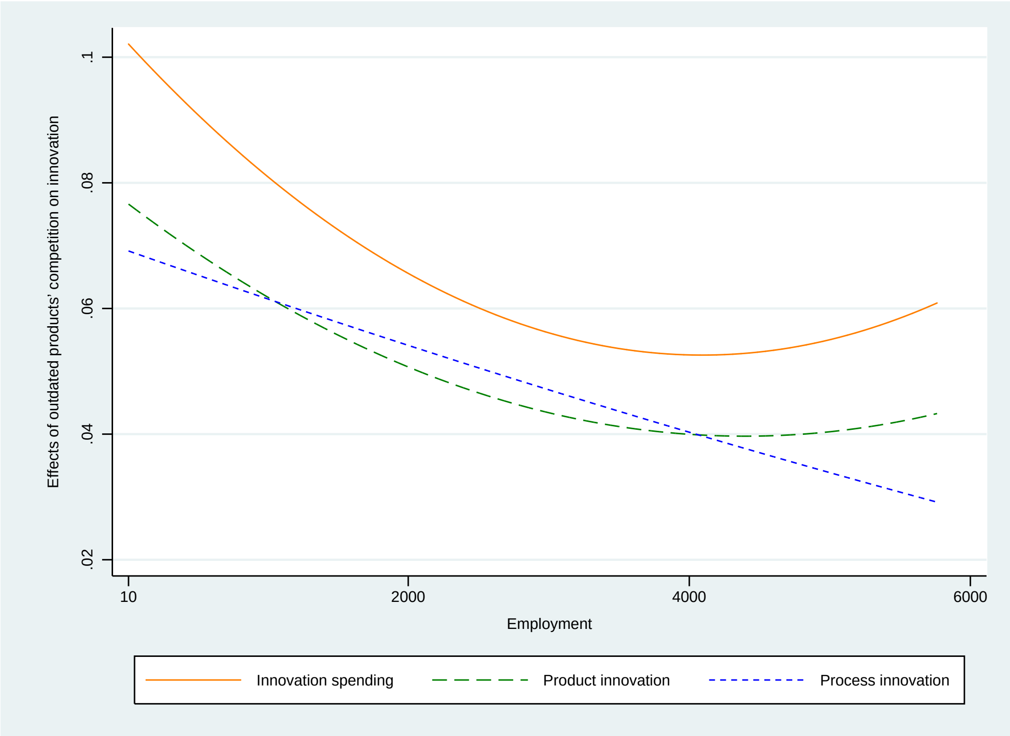
Significance levels : $\dagger$: 10% $*$: 5% $**$: 1%

Table 7: FIML estimates of the relation between perceived competition and technological innovation: Dynamic model

Variable	APE	Std. Err.	APE	Std. Err.
	no pseudo fixed-effects		with pseudo fixed-effects	
	Innovation spending			
Innovation spending$_{t-1}$	0.332**	0.038	0.262**	0.039
Perceived competition$_{t-1}$				
PC 1	0.002	0.030	0.002	0.030
PC 2	0.025	0.034	0.018	0.033
PC 3	0.098**	0.035	0.103**	0.035
PC 4	-0.003	0.032	-0.015	0.031
Local conglomerate	0.104**	0.039	0.089*	0.039
Multinational enterprise	-0.008	0.034	-0.035	0.036
Employment (in log)	0.049**	0.012	0.069**	0.013
Univ. degree of emp.				
[5%, 50%]	0.186**	0.039	0.142**	0.039
>50%	0.203**	0.044	0.209**	0.053
Subsidies$_{t-1}$	0.074†	0.043	0.041	0.044
	Product innovation			
Product innovation$_{t-1}$	0.141**	0.029	0.106**	0.028
Innovation spending	0.676**	0.046	0.655**	0.050
Innovation spending$_{t-1}$	0.224**	0.030	0.173**	0.028
Perceived competition$_{t-1}$				
PC 1	0.001	0.020	0.001	0.019
PC 2	0.017	0.023	0.012	0.022
PC 3	0.066**	0.024	0.068**	0.023
PC 4	-0.002	0.021	-0.010	0.020
Local conglomerate	0.098*	0.040	0.088*	0.040
Multinational enterprise	0.029	0.035	-0.002	0.037
Employment (in log)	0.064**	0.012	0.081**	0.013
Univ. degree of emp.				
[5%, 50%]	0.126**	0.028	0.094**	0.027
>50%	0.137**	0.031	0.138**	0.036
Subsidies$_{t-1}$	0.050†	0.029	0.027	0.029
	Process innovation			
Process innovation$_{t-1}$	0.070**	0.027	0.048†	0.026
Innovation spending	0.581**	0.044	0.625**	0.041
Innovation spending$_{t-1}$	0.193**	0.027	0.164**	0.027
Perceived competition$_{t-1}$				
PC 1	0.001	0.017	0.001	0.018
PC 2	0.015	0.020	0.011	0.021
PC 3	0.057**	0.021	0.065**	0.022
PC 4	-0.002	0.018	-0.009	0.019
Local conglomerate	0.068†	0.040	0.096*	0.041
Multinational enterprise	0.091*	0.036	0.081*	0.039
Employment (in log)	0.075**	0.012	0.078**	0.013
Univ. degree of emp.				
[5%, 50%]	0.108**	0.024	0.089**	0.025
>50%	0.118**	0.027	0.131**	0.034
Subsidies$_{t-1}$	0.043†	0.025	0.026	0.027
Industry dummies	no		yes	
Time dummies	yes		yes	
Log-likelihood	-1191.390		-1134.506	
# observations	868			

Significance levels : $\dagger$: 10% $*$: 5% $**$: 1%

Figure 1: Partial effects of perceived competition on technological innovation versus employment



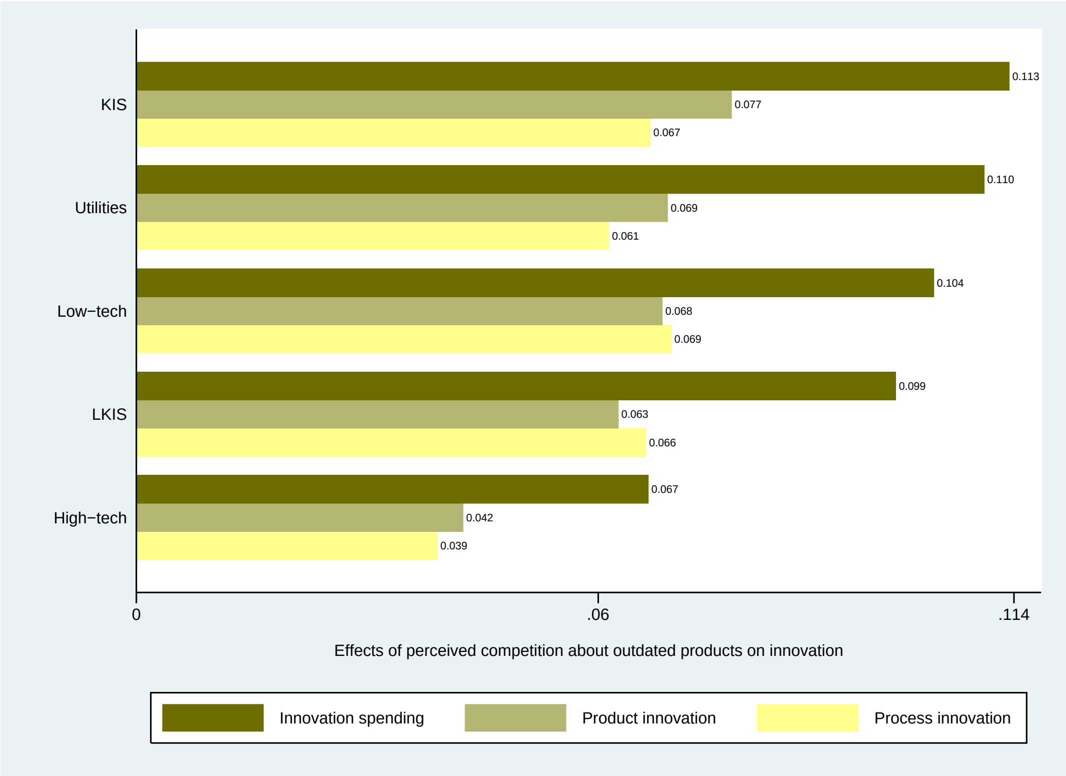
or services, smaller firms have more the urge to innovate (and actually achieve so) than larger counterparts since the latter are known to be more diversified than the former (see e.g. Aron, 1988). According to Figure 2, firms that operate in the high-technology sector have on average a significantly lower propensity to invest in innovation and actually achieve product and process innovations when faced with higher competition than the remaining sectors. This propensity is not significantly different across the remaining sectors.

4.2 Policy recommendations

Many lessons can be learned from the above results as regards to policy recommendations. First, there is no causal effect of subsidies on innovation activities and innovation success. Furthermore, while subsidised enterprises are observed to belong primarily to the high-technology sector and to be very large (see e.g. Lach, 2002),[20] the effect of subsidies on innovation spending is the lowest in the high-technology sector and in the category of large firms (see Figures 3 and 4). Therefore, the current targeting procedure for direct subsidies is

[20] The percentage of subsidised enterprises in the high-technology sector over the 2002-2010 period is 53%. This percentage varies from 23% to 45% in the remaining sectors. Furthermore, 44% of large firms (above 250 employees) are subsidy recipients as compared to 34% of medium-sized enterprises (between 50 and 250 employees) and 24% of small firms (smaller than 50 employees).

Figure 2: Partial effects of perceived competition on technological innovation by sector



counterproductive and needs to be revised. For instance, knowledge-intensive services (KIS) and medium-sized enterprises could be more often targeted. Second, any policy instrument to encourage innovation investment (e.g. tax credit) should primarily target enterprises that belong to a local conglomerate as opposed to independent and multinational enterprises. Independent enterprises benefit less from knowledge spillovers than local conglomerate enterprises, and MNEs are more likely to set up their R&D units elsewhere on the basis of "dynamic efficiency" (see Meyer-Krahmer and Reger, 1999). Local conglomerate enterprises also consist mainly of medium-sized enterprises (50%), which confirms the importance of this target category to policy makers. Third, as already seen in Figure 2, any competition policy instrument to promote innovation in the high-technology sector would be counterproductive. On the contrary, given the high level of concentration and the low level of innovation (see Table 2), and the large potential effect of competition on innovation in the utilities sector (see Figure 2), the latter is an ideal target for promoting competition and hence innovation therein.

Figure 3: Partial effects of subsidies on innovation by sector

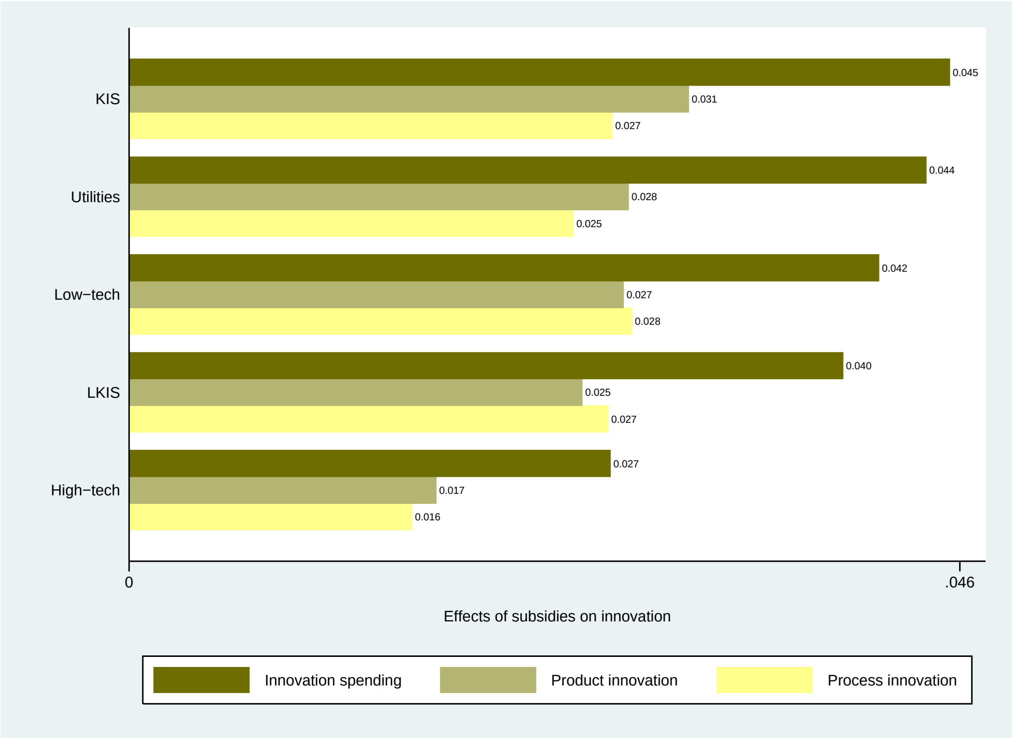
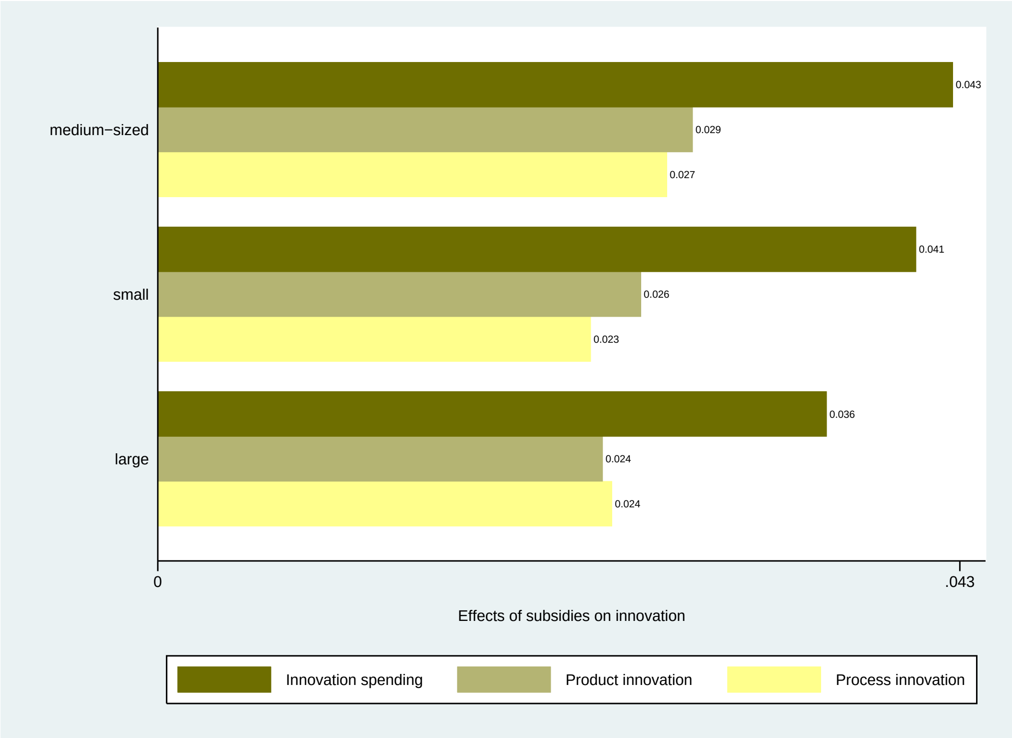


Figure 4: Partial effects of subsidies on innovation spending by size class



5 Conclusion

This paper has shed some light on the relation between competition and innovation in Luxembourg using a panel of enterprise data over the period 2002-2010. Using four measures of perceived competition and three indicators of innovation, we have estimated a nonlinear dynamic simultaneous-equations model and obtained the following results. First, perceived competition with respect to obsolete products or services Granger-causes innovation activities and eventually innovation success. Second, the threat of seeing the arrival of new competitors and easy substitution of products has no significant effect on innovation activities and innovation success. Third, the enterprise facing rapidly-changing technologies in the market eventually faces the threat of seeing its products or services obsolete. This enterprise has a higher propensity to invest in innovation and eventually becomes more successful in achieving product or process innovations. Fourth, the effect of competition on innovation activities decreases with firm size, i.e., the larger the firm the lower the urge to innovate when faced with competition. Fifth, firms in the high-technology sector have the lowest propensity to innovate under competition. As additional results, we have also found that, *ceteris paribus*, direct subsidies do not Granger-cause innovation. In other words, subsidised firms are neither more innovative nor more successful than non-subsidised counterparts. On the contrary, larger enterprises and those with a better skilled labour force have a larger probability to invest in innovation and to be technologically successful. Similarly, local conglomerate enterprises are more likely to spend in innovation and to successfully introduce product innovations than independent firms and multinational enterprises (MNEs).

Many lessons can be learned from the results as far as policy recommendations are concerned. First, the current targeting procedure for direct subsidies to encourage innovation, which consists in selecting mainly large and high-tech sector firms, is counterproductive and needs to be revised. The results suggest, for instance, that medium-sized and KIS enterprises could be more often targeted. Second, any policy instrument that encourages innovation investment (e.g. tax credit) should primarily target local conglomerate enterprises as opposed to independent and MNEs. Finally, any competition policy instrument to promote innovation in the high-tech sector would also be counterproductive. Instead, allowing more competition in the utilities sector would result in more innovation activities. In the light of these results, the Luxembourgish manufacturing high-technology sector should be scrutinised as far as direct subsidies, competition and innovation are concerned.

References

Agarwal, R., Audretsch, D. B., 2001. Does entry size matter? The impact of the life cycle and technology on firm survival. Journal of Industrial Economics 49, 21–43.

Aghion, P., Bloom, N., Blundell, R., Griffith, R., Howitt, P., 2005. Competition and innovation: An inverted-U relashionship. Quarterly Journal of Economics 120, 701–728.

Aron, D. J., 1988. Ability, moral hazard, firm size and diversification. RAND Journal of Economics 19, 72–87.

Arrow, K. J., 1962. Economic welfare and the allocation of resources for invention. In: Nelson, R. (Ed.), The Rate and Direction of Inventive Activity: Economic and Social Factors. Princeton University Press (for NBER), pp. 609–626.

Baltagi, B. H., 2008. Econometric Analysis of Panel Data, 4^{th} Edition. John Wiley & Sons.

Bérubé, C., Duhamel, M., Ershov, D., 2012. Market incentives for business innovation: Results from Canada. Journal of Industry, Competition and Trade 12, 47–65.

Bhattacharya, S., Ritter, J. R., 1983. Innovation and communication: Signalling with partial disclosure. Review of Economic Studies 50, 331–346.

Bonanno, G., Haworth, B., 1998. Intensity of competition and the choice between product and process innovation. International Journal of Industrial Organization 16, 495–510.

Boone, J., 2000. Competitive pressure: The effects on investments in product and process innovation. RAND Journal of Economics 31, 549–569.

Boone, J., 2008. A new way to measure competition. Economic Journal 118, 1245–1261.

Boone, J., van Ours, J. C., van der Wiel, H., 2012. When is the price cost margin a safe way to measures changes in competition? De Economist 161, 45–67.

Cefis, E., Orsenigo, L., 2001. The persistence of innovative activities: A cross-countries and cross-sectors comparative analysis. Research Policy 30, 1139–1158.

David, P. A., Hall, B. H., Toole, A. A., 2000. Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. Research Policy 29, 497–529.

Dosi, G., Marengo, L., 1994. Some elements of an evolutionary theory of organizational competencies. In: England, R. W. (Ed.), Evolutionary Concepts in Contemporary Economics. Michigan University Press, Ann Arbor, pp. 157–178.

Flaig, G., Stadler, M., 1994. Success breeds success. The dynamics of the innovation process. Empirical Economics 19, 55–68.

Futia, C. A., 1980. Schumpeterian competition. Quarterly Journal of Economics 94, 675–695.

Geroski, P. A., van Reenen, J., Walters, C. F., 1997. How persistently do firms innovate? Research Policy 26, 33–48.

Gilbert, R., 2006. Looking for Mr. Schumpeter: Where are we in the competition-innovation debate? In: Jaffe, A. B., Lerner, J., Stern, S. (Eds.), Innovation Policy and the Economy. Vol. 6. MIT Press, Ch. 6, pp. 159–215.

Habiyaremye, A., Raymond, W., 2013. Transnational corruption and innovation in transition economies. UNU-Merit Working Paper Series #2013-050.

Heckman, J. J., 1981. Statistical models for discrete panel data. In: Manski, C. F., McFadden, D. (Eds.), Structural Analysis of Discrete Data with Econometric Applications. Cambridge, MA: MIT Press, pp. 114–178.

Lach, S., 2002. Do R&D subsidies stimulate or displace private R&D? Evidence from Israel. Journal of Industrial Economics 50, 369–390.

Levin, R. C., Cohen, W. M., Mowery, D. C., 1985. R&D appropriability, opportunity, and market structure: New evidence on some Schumpeterian hypotheses. American Economic Review 75, 20–24.

Máñez, J. A., Rochina-Barrachina, M. E., Sanchis, A., Sanchis, J. A., 2009. The role of sunk costs in the decision to invest in R&D. Journal of Industrial Economics 57, 712–735.

Mansfield, E., 1968. Industrial Research and Technological Innovation: An Econometric Analysis. W. W. Norton & Company, New York.

Meyer-Krahmer, F., Reger, G., 1999. New perspectives on the innovation strategies of multinational enterprises: Lessons for technology policy in Europe. Research Policy 28, 751–776.

Nelson, R. R., Winter, S. G., 1982. An Evolutionary Theory of Economic Change. Harvard University Belnap Press, Cambridge, MA.

Neyman, J., Scott, E. L., 1948. Consistent estimates based on partially consistent observations. Econometrica 16, 1–32.

Peneder, M., 2012. Competition and innovation: Revisiting the *inverted-U* relationship. Journal of Industry, Competition, and Trade 12, 1–5.

Peroni, C., Gomes Ferreira, I. S., 2012. Competition and innovation in Luxembourg. Journal of Industry, Competition and Trade 12, 93–117.

Peters, B., 2009. Persistence of innovation: Stylised facts and panel data evidence. Journal of Technology Transfer 34, 226–243.

Polder, M., Veldhuizen, E., 2012. Innovation and competition in The Netherlands: Testing the inverted-U for industries and firms. Journal of Industry, Competition, and Trade 12, 67–91.

Scherer, F., 1967. Market structure and the employment of scientists and engineers. American Economic Review 57, 524–531.

Schumpeter, J. A., 1942. Capitalism, Socialism and Democracy. Harper and Brothers, New York.

Tang, J., 2006. Competition and innovation behaviour. Research Policy 35, 68–82.

Tingvall, P. G., Poldhal, A., 2006. Is there really an inverted U-shaped relation between competition and R&D? Economics of Innovation and New Technology 15, 101–118.

Veugelers, R., Cassiman, B., 2004. Foreign subsidiaries as a channel of international technology diffusion: Some direct firm level evidence from Belgium. European Economic Review 48, 455–476.

Wallsten, S. J., 2000. The effects of government-industry R&D programs on private R&D: The case of the small business innovation research program. RAND Journal of Economics 31, 82–100.

Wright, J. D., 2011. Antitrust, multidimensional competition, and innovation: Do we have an antitrust-relevant theory of competition now? In: Manne, G. A., Wright, J. D. (Eds.), Regulating Innovation: Competition Policy and Patent Law Under Uncertainty. Cambridge University Press, pp. 228–251.