Innovativeness along the business cycle

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Abstract

As of today, the international literature has significantly contributed to the comprehension of the mechanisms underlying the innovative behaviour of firms, its impact on performance and, to a lesser extent, the inertia inherent to the phenomenon. On the opposite, the dynamics of knowledge-capital accumulation along the business cycle still remains an unexplored topic. We here start to analyse this dimension of innovation within the benchmark proposed in 1998 by Crépon, Duguet and Mairesse using a balanced panel of medium and large Uruguayan firms. Our findings reveal that, on average, the innovation intensity evolves procyclically while the innovation propensity and the novelty degrees follow a counter-cyclical path. The type of innovation sought during economic recessions is heterogeneous across firms. Innovators that are able to divert their sales to world markets tend to innovate in products of enhanced originality while those oriented to the local market generally innovate in processes of a low novelty degree. The results also suggest that the productivity gains that are driven by significantly relevant innovations along the upswing, regardless of their type, are less substantial than those achieved along the downturn are.

Keywords:

Innovative behaviour; CDM model; returns to innovation; business cycle

JEL: O31; O32

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Innovativeness along the business cycle

Adriana Cassoni and Magdalena Ramada-Sarasola

1. Introduction

Most of the applied work on the innovative behaviour of firms is currently performed within the framework proposed in 1998 by Crépon, Duguet and Mairesse. Nevertheless, data non-availability frequently prevents to specify models fully mirroring the original formalisation - the 'CDM model'.

The reported evidence serves to characterise the innovative profile of firms and also to provide policy-makers with most relevant insights on the drivers and deterrents of knowledge accumulation. Since the vast majority of studies are carried out using firm-level information for one or several economies, they also allow for the comparison of innovation technologies across countries in the long run. Temporal trends are in turn identified performing comparative statics whenever two or more waves of innovation surveys are available.

On the opposite, the dynamics of the overall knowledge accumulation process have been rarely explored. With one notable exception (Vancautereny *et al*., 2011), the literature focuses on the temporal trends inherent to a specific stage of the decision process while analyses over the same sample of firms in time are yet to be done.

The characteristics of the datasets that are generally used (sample units and time-spans) also prevent to explore the role of innovation activities along the business cycle. We here contribute to this particular dimension of knowledge accumulation by providing insights on the behaviour of medium and large Uruguayan firms that operated along 1997 to 2006, a 10-years window that accounts for an almost complete economic cycle.[1]

In the next section we briefly review some of the relevant literature on the topic. In Section 3 we describe the reported stylised facts for Uruguay and we afterwards characterise the balanced panel of firms used in the analysis. The specification of the empirical CDM model for Uruguay and the estimation results are discussed in Section 5. We summarise the main conclusions in the final section.

2. Brief review of the empirical literature on innovation

Major constraints to growth that are universally cited in the literature include low human capital endowments; insufficient provision of public goods; inadequate regulatory frameworks; and/or macroeconomic instability. Once these obstacles are overcome, development becomes feasible through the shift to higher value-added production patterns driven by knowledge accumulation (Schumpeter, 1957). It is thus possible to treat the knowledge-capital stock as an additional production factor and assimilate its impact on output growth to the returns to innovation (Griliches, 1979).

[1] The slowdown of the Uruguayan economy started in 1998. In 2002-03 the country went through the deepest financial crisis in its economic history but regained a prosperous path by 2004. Even though the growth rate decelerated in 2008, the similar levels of gross domestic product observed in 2006 and 1998 imply that ignoring the two final years of the cycle would not result in a significant loss of information.

The early empirical literature performed within this frame estimated the returns to innovation using production/productivity models that included accumulated R&D investments as a proxy for knowledge-capital (see the survey in Hall and Mairesse, 2006). The reported evidence within this benchmark has been however questioned by noting that R&D stocks would only eventually give rise to innovations while identical endowments may result in different innovation outputs whenever the production technologies - the knowledge production functions (KPFs) – are distinct across firms (Pakes and Griliches, 1984).

Crépon *et al*. (1998) provided further insights to the understanding of knowledge accumulation processes by arguing that the mechanisms through which the resources spent in R&D are decided upon also encompass relevant information on the innovative behaviour of firms. The authors differentiate between three distinct stages within the overall knowledge accumulation process and propose to formalise it as a recursive system of equations - the CDM model.

According to the CDM proposal, at an initial stage entrepreneurs decide whether or not to engage in innovative activities while the amount of resources to be invested by those that have self-selected themselves as innovative is decided upon at a second stage. In both cases, the decision taken is assumed to depend on the prevailing macroeconomic conditions, market structure and firm characteristics. The rationale is thus consistent with the existence of a large number of non-innovative firms in all economies, regardless of their level of development, as well as with the heterogeneous investment levels observed across innovators.

These two instances are formalised in the original paper as equations (1) and (2) below:

$$\text{If } g_i^* \geq C^*_i \;\Rightarrow\; g_i = \boldsymbol{X}_{1i}\boldsymbol{\beta}_1 \qquad \text{while if } g_i^* < C^*_i \;\Rightarrow\; g_i = 0 \qquad (1)$$

$$\text{If } g_i \neq 0 \;\Rightarrow\; k_i = \boldsymbol{X}_{2i}\boldsymbol{\beta}_2 \qquad \text{while if } g_i = 0 \;\Rightarrow\; k_i = 0 \qquad (2)$$

Where g^*_i is a latent variable denoting firm *i*'s propensity to innovate; C^*_i is a certain threshold; g_i is the actual innovation propensity and hence it is observed only whenever g^*_i exceeds C^*_i. The innovation investment is denoted by k_i; and vectors $\boldsymbol{X}_{1i}$ and $\boldsymbol{X}_{2i}$ include the set of firm, market and macroeconomic variables that are assumed to influence both decisions.

It is worth to note that the specification of the second equation implies that the firm's innovation effort is unrelated to any economic optimisation process. The condition may be highly binding under several but not all scenarios, such as when firms need to comply with regulations linked to health, safety and environmental issues or with certain national/international restrictions associated to quality and/or technological standards. The hypothesis would also be in place when the decision to invest on innovation is not taken by the firm itself but by related agents, such as partners of an economic group or the parent company of which the firm is a local branch or subsidiary.

Given the innovation investment, the resulting R&D stock ($\sum^t k_{it}$) is included in the KPF so as to generate a novel output - t_i – that is also allowed to differ across firms with distinct characteristics, operating in different markets and/or that face divergent macroeconomic environments (the corresponding variables are included in vector $\boldsymbol{X}_{3i}$). The proposed model is stated in logs as:

$$\text{If } k_{it} \neq 0 \ \ (g_i \neq 0) \ \Rightarrow \ \ t_i = \sum^{t} k_{it}\, \alpha + \boldsymbol{X}_{3i}\boldsymbol{\beta}_3 \qquad \text{while if } \ k_{it} = 0 \ \ (g_i = 0) \ \Rightarrow \ \ t_i = 0 \qquad (3)$$

The innovation output so obtained is assumed to increase the pre-existent stock of knowledge-capital – KC – that in turn enters the firm's overall production function as an additional input. Choosing labour productivity - q_i – as the indicator of the firm's economic performance and assuming a Cobb-Douglas technology, the output elasticity with respect to knowledge-capital (σ) is measured by estimating equation (4) below, where other production factors – labour, physical capital and intermediate consumption – are gathered in vector $\boldsymbol{Z}_i$ while firm, market and macroeconomic specificities are included in vector $\boldsymbol{X}_{4i}$:

$$lnq_i = \sigma lnKC_i + ln\boldsymbol{Z}_{i*}\boldsymbol{\lambda} + \boldsymbol{X}_{4i*}\boldsymbol{\beta}_4 \qquad (4)$$

Data non-availability has frequently forced researchers to specify a modified version of the KPF, using as the dependent variable either the ratio of the innovation output to employment or the value of innovations over sales (as a proxy for the rate of growth of knowledge-capital). Equation (2) is in turn re-stated in terms of the innovation intensity or else the financial effort devoted to innovation activities (i.e., the ratio of the innovation expenditure over employment or total sales).

Regardless of the chosen specification, the international evidence on firms' innovation propensity and intensity has identified several fostering factors of both external and internal to the firm nature (Crépon *et al.*, 1998; Crespi and Zuñiga, 2010; Griffith *et al.*, 2006; Raffo *et al.*, 2008; and references therein). The institutional and/or environmental features included in the empirical models that have proven to be significant drivers of innovation relate to the access to information and external funding from diverse sources (public, international, academic and/or economic agents, among other); the existence or not of a property-rights protection system; and several 'demand pull' aspects that range from quality standards to regulations of various types. Relevant internal characteristics involve the firm's size (large); its accumulated experience on innovation activities; the skill-level of workers (high); its participation from largely competitive markets; and the full/partial foreign ownership of the company.

Most of the research performed using the CDM model for Europe, US, Canada and some Asian countries do find a positive relationship between the innovation effort and the resulting output and are also able to identify significant returns to innovation (for a review of the literature see, e.g., Arundel *et al*., 2003; Hall and Mairesse, 2006). Country comparisons - as those done in Griffith *et al*. (2006) for France, Germany, Spain and Britain; in Janz *et al*. (2003) for Germany and Sweden; or in Raymond *et al*. (2010) for France and The Netherlands; and those reviewed in Stoevsky (2005) - suggest that the elasticities of interest do not significantly differ among developed economies: the estimated output-input elasticities and the returns to innovation vary within (0.2 to 0.4) and (0.1 and 0.3), respectively.

Due to data availability but also to the type of innovation output attained by most firms, the research in developed countries has generally focused on product innovation. The impact of novel processes has at times been accounted for by assuming that it is materialised only in a scale effect (one early example is Van Leeuwen and Klomp, 2006).

At the other end, the research for Latin America following the original CDM proposal is almost inexistent, notable exceptions being Benavente (2004; 2006) for Chile; and Cassoni and Ramada-Sarasola (2010; 2012) for Uruguay. While no links are identified in the Chilean case, the relevant parameters for Uruguay are indeed found to be significant and their size (between 0.1 and 0.2) is quite in line with that reported by the existing international literature. The use of different proxy variables for the innovation output is one most likely explanation for these uneven results: while Benavente (2004; 2006) uses the innovative share of sales, Cassoni and Ramada-Sarasola (2010; 2012) define alternative measures that differentiate across novelty degrees and that further assign innovative processes the relevance they ought to have when they are the bulk of innovation activities.

An extension of the CDM model that has become relatively frequent involves the use of a broader definition of the innovation input that encompasses other factors apart from R&D, such as industrial and engineering design; new training programmes; and the acquisition of novel physical capital (OECD and Eurostat, 1997). However, the theoretical and empirical consequences of their separate inclusion in the KPF have received little attention up to now.

A branch of the empirical literature follows a divergent path and models the odds of attaining an innovation output instead of the KPF. Even though the approach is unable to link the observed heterogeneity in innovation output values to the technical features of production, it does provide with relevant insights on other dimensions of the phenomenon. In particular, the balanced treatment of products and processes allows for identifying their differentiated effects on productivity.

Novel procedures are found to exert an extra impact on productivity growth rates in the case of Spain (Huergo and Jaumandreu, 2004) and several small economies (Czarnitzki and O'Byrnes, 2007 for Flanders; Lee and Kang, 2007 for South Korea; Masso and Vahter, 2008 for Estonia). Some evidence is also found for Latin American countries although the divergence among the reported results prevents from building a robust case for the region, both within and across countries (a thorough survey can be found in Hall and Maffioli (2008) and in Crespi and Zuñiga (2010), while case studies worth to be cited include Arza and López (2010), Chudnovsky *et al.* (2006), and López and Orlicki (2006) for Argentina; De Negri *et al.* (2007) and Goedhuys (2007) for Brazil; Alvarez *et al.* (2010) for Chile; Hernández Umaña (2005) for Colombia; Pérez *et al.* (2005) for Mexico; Bianchi *et al.* (2008) and Cassoni and Ramada-Sarasola (2010) for Uruguay.

Even though the understanding of the innovative behaviour of firms has gone a long way during the last decade, at least in the case of firms in developed countries focused on product innovation, there is still a large black hole regarding some key features.

A first major issue relates to the meagre characterisation of the innovation technology and the consequent insufficient understanding of the economic rationale that underlies the innovation investment decisions. The oversimplified specification of the KPF – stated in terms of either the total innovation expenditure or a sole input (R&D) – implies that the input composition of the innovation expenditure plays no role on the outcome of innovation activities. However, since the risks associated to the time-horizon of investment vary across inputs, differences in their relative shares may affect the generation of innovations in a distinct manner while complementarities among them are ruled out from the outset (Mairesse and Sassenou, 1991). Composition effects may also be influential within the innovation intensity equation given that a less concentrated expenditure could decrease the risks of failure in the same fashion diversification works for a financial portfolio.

Secondly, the poor modelling of new procedures is most likely to yield inaccurate predictors of innovation output values and hence biased estimates of the returns to innovation, particularly when they are the core of knowledge accumulation practices. The most urgent task in this respect seems to be the definition of adequate indicators for the value of novel procedures based on the existing data, even though significant improvements may only be achieved by collecting additional information through innovation surveys.

The empirical analysis of the dynamics of innovation is a third pending matter of utmost relevance that prevents models to account for the learning-by-doing process inherent to knowledge-capital accumulation. Some progress has been gained through the study of persistence patterns by exploring whether the odds to introduce an innovation are higher or not for firms that have already innovated in the past (Alfranca *et al.*, 2002; Cefis, 2003; Geroski *et al.*, 1997; Peters, 2009; Raymond *et al.,* 2006, among others), or else by identifying persistent effects of innovations on firm performance (Antonelli *et al*., 2012; Bartoloni, 2010, Cefis and Ciccarelli 2005; Latham and Le Bas, 2006). Alternatively, the inertia of innovation effects have been analysed with models that explicitly account for their structure under the premise that the dynamics of knowledge-capital accumulation are heterogeneous across firms that differ in terms of certain technology-related aspects (Colombelli and Quatraro, 2012; Quatraro, 2012).

These approaches are however uninformative with respect to the dynamics embedded in the decision process that leads to a particular composition of the total innovation input and to its linkages with the resulting type(s) of output. In contrast, Vancautereny *et al*. (2011) explore these mechanisms for an unbalanced panel of Dutch firms using a dynamic model inspired in the original CDM specification. Persistence effects are identified in the innovation intensity and in the KPF but their findings are mixed with respect to the impact of knowledge-capital on productivity.

The above issues are dealt with in this paper with unequal strength. Our main target is to analyse the mechanisms underlying innovation practices along the economic cycle. As a first approach to the topic, we focus on the behaviour of a balanced panel of Uruguayan manufacturing firms and thus leave unaddressed the characterisation of new entrants and exits. We also restrict this initial study to the behaviour of medium and large companies due to the sampling model used in the surveys. We perform the analysis within the frame proposed in Crépon *et al*. (1998) although also indirectly accounting for dynamic effects. We use innovation output indicators that give a balanced treatment to novel products and processes and we differentiate among the impact of diverse input mixes in both the intensity equation and the KPF using the indicators proposed in Cassoni and Ramada-Sarasola (2012).

3. Stylised facts for Uruguay

The sluggish dynamism that characterises the innovative behaviour of most Uruguayan firms is generally considered to be at the root of the country's inability to boost development even though it has undergone through several long-lasting periods of substantial prosperity (see Arocena and Sutz, 2008 for a discussion on the topic). Actual knowledge-capital stocks have been far below the international levels (Hall and Maffioli, 2008; Hausmann *et al*., 2005) while the gap has not decreased in time (Arocena or Sutz, 2008).

The type of novel output attained is an additional differentiating feature with respect to developed economies, where the major emphasis is set on the generation of new products (Bloch *et al.*, 2007). Indeed, process-innovators have always been at least 90% of innovative firms in Uruguay (Cassoni, 2012), while the share of those that only innovate in processes substantially increased after the 2002 crisis (from 34% in 2003 to 53% in 2006). Given that most novel procedures are just new-to-the firm (75%), particularly when they are the sole type of output sought, and that only a minor share of them constitute world-level innovations (7%), the inability of Uruguay to catch up with the international standards should come at no surprise.

The average innovation propensity of firms varies between 30% and 40% along 1998-2006 in a counter-cyclical manner (the share of innovative firms in 2000 being 35%).[2] Even though the percentages are larger than the shares reported by Raffo *et al*. (2008) for all firms in two of the largest Latin American economies in 2000 - Brazil (25%) and Mexico (18%) -, they are still half-way developed countries' rankings (see, e.g., the statistics included in the OECD Eurostat yearbooks).

These differing propensities are not however related to a low degree of success across Uruguayan innovators, since at least 97% of them are able to attain a novel output within a 3-year period according to Innovation Surveys' data. They are instead the reflection of the structurally high degree of risk aversion that characterise most Uruguayan entrepreneurs that are hence largely reluctant to engage in projects with a long-term investment horizon and/or that involve unexplored activities.

In contrast, the innovation propensity among corporations, exporters, non-full national firms and large companies are much more similar to those observed in developed economies (50% to 75%) while at least 30% of innovators within these subsets have generated international market-level

[2] The figures here reported are all calculated taking into account the design of the sample (see Fazio *et a*l., 2008 *et al.* for a discussion on the topic) and are thus at times different from those reported in other publications that disregard such effects.

innovations along the period analysed (Cassoni, 2012).

On the other hand, the introduction of processes of low novelty degrees (probably seeking to reduce costs) seems to be a most suitable means to cope with economic recessions in Uruguay, as revealed by the fact that the bulk of innovators that switched from products to processes after 2003 are fully or partially owned by national entrepreneurs that operate in the local market. The hypothesis is also consistent with the 25% to 30% of large enterprises, multinationals and full-exporters that generated new to the world innovations in 2003, suggesting that they engaged in product innovations so as to divert their local sales to world markets (Cassoni, 2012; Cassoni and Ramada-Sarasola, 2010).

According to the literature on Uruguay (Arocena and Sutz, 2008; Bértola *et al*., 2005; Bianchi and Gras, 2005; Bianchi *et al*., 2008; Hall and Maffioli, 2008; Hausmann *et al*., 2005), the major drivers of innovation relate to the firms' access to financial-aid; the definition of public policies with a generalised outreach; the creation of relevant clusters of firms as a vehicle to enhance the effects of public policies; and the promotion of cooperation through information networks and/or through the National System of Innovation (NSI).

The few research studies framed within the CDM model show, however, that the above-hypothesised dimensions become significantly less relevant compared to those linked to the firm's operational efficiency and/or its production technology, at least under favourable macroeconomic conditions (Cassoni and Ramada-Sarasola, 2010; 2012). Once these factors are controlled for, the identified deterrences for innovation only refer to the lack of relevant information and to the existence of market-related barriers.

Similarly, differences in the innovation intensity across firms with and without access to external funds are less pronounced compared to those associated to a divergent composition of the total innovation expenditure and to its degree of diversification. Other things equal, the largest financial effort would be observed across firms that invest in physical capital and with a largely concentrated expenditure. Yet, those that invest in R&D and that most diversify their investment would attain innovations with the highest novelty degrees (Cassoni and Ramada-Sarasola, 2010; 2012).

4. The balanced panel of firms

4.1. The definition of the sample

Available data on innovation activities stem from three waves of the Innovation Survey (IS) performed in 2000; 2003 and 2006 on the same sample of manufacturing firms used in the Annual Economic Activity Survey (EAS). The definition of the EAS's sample is such that all medium and large firms are of mandatory inclusion while small enterprises are selected using a stratified sampling model. A firm is considered 'small' whenever it has less than 50 workers or else when the level of its sales is below a certain threshold (that varies in time).

Our dataset has 1209 observations that refer to 403 enterprises that, being of mandatory inclusion in the EAS samples, have participated in the market all along the 1997-2006 period. These firms account for 82% of the total sub-population of non-small companies as well as for 52% of all sampled units. Therefore, the behavioural patterns of firms in the balanced panel reflect only those that prevail in the sub-population of medium and large firms that were borne before 1998 and that have survived at least until 2006. They cannot be thus considered as representative of the behaviour of small firms nor of those that entered or left the market along the period.

4.2. Innovations and innovators

We classify innovations in two types - products and processes – thus setting no distinction between the three categories of novel procedures reported in the IS – productive, organisational and commercialisation-related. Based on this classification, we define two subsets of innovative firms depending on whether or not they innovate in products - ‘product-innovators’ and ‘only-process-innovators’.

We also aggregate the nine types of innovation inputs reported in the surveys in four categories that are not only theoretically consistent but that are able to preserve, within each size and economic sector stratum, the characteristics of the statistical distribution of firms that invest in each input according to the original classification. The re-defined innovative inputs are: (i) ‘R&D’, internal or external to the firm; (ii) physical capital, hardware and software – ‘KHS’; (iii) training programmes of any sort – ‘TP’; and (iv) engineering & industrial design, technology transfers and consultancy services – ‘DTC’.

Medium and large firms that survived along 1997-2006 are characterised by a high propensity to innovate that drops sharply during the downturn – from 73% to 60% - and goes on decreasing at a slower pace thereafter. Since the rate of success is most stable along the period (98%), the share of innovators follows the same temporal path (Table 1).

The behaviour of firms in the balanced panel suggests that small firms engage in innovation activities as a means to sort adverse shocks to a greater extent than large companies do (the innovation propensity is counter-cyclical for the total sample of firms) while the opposite holds once the economy regains a prosperous path (the overall decline in 2006 is sharper – 18% - relative to that observed within our panel - 8%).

Further, given the 2003-drop in the innovation propensity within our sub-sample (-18%) is opposed to the increased innovativeness registered among all medium and large firms (+9%, according to Cassoni, 2012), the results also suggest that at the economic recession large-sized new entrants were more prone to innovate than those enterprises already in the market. On the other hand, the generalised switch of firms towards innovating in just one type of output observed for the total sample in 2006 is also present in our sub-sample (Table 1), in which the decline in the number of innovations with respect to 2003 (26%) is much larger relative to that of innovators (8%).

Table 1. Distribution of firms by innovation input and output types 1998-2006

	2000	2003 (number)	2006	2000	2003 (%)	2006
Total firms	403	403	403	100	100	100
Innovative firms	294	240	221	73	60	55
Innovators	285	237	218	71	59	54
Innovators by output						
Products-only	11	11	26	4	5	12
Processes-only	105	82	90	37	35	41
Products & Processes	169	144	102	59	61	47
Products & Productive Processes	157	140	92	55	59	42
Distribution of total innovations by type	634	536	396	100	100	100
Products	180	155	128	28	29	32
Productive Processes	236	203	154	37	38	39
Non-Productive Processes	218	178	114	34	33	29

Source: Own calculations based on data from the Innovation Surveys 1998-00; 2001-03 and 2004-06, ANII/DiCyT/INE.

The comparative evolution of novelty degrees depicted in Table 2 with those reported by Cassoni (2012) in turn suggests that the increased propensity to innovate in processes of low relevance, particularly at the bottom of the cycle, is more widespread across small than large firms. Indeed, even though the counter-cyclical pattern of new-to-the-firm processes is also present in our sub-sample (at most in 68% of cases), the percentages are substantially below those that characterise small companies (at least 95%). The opposite holds in turn with respect to the share of innovators that attain new to the world innovations all along the period - 9%, 5% and 13% for the total sample (Cassoni, 2012).[3]

Table 2. Distribution of innovations by type and by degree of novelty 1998-2006

	2000	2003 (number)	2006	2000	2003 (%)	2006
Total output	634	536	396	100	100	100
New to the firm	356	323	184	56	60	46
New to the local market	181	157	136	29	30	35
New to the international market	97	56	76	15	10	19
Innovative Products	180	155	128	100	100	100
New to the firm	96	80	41	54	52	32
New to the local market	51	47	51	28	30	40
New to the international market	33	28	36	18	18	28
Innovative Productive Processes	236	203	154	100	100	100
New to the firm	132	122	78	56	60	51
New to the local market	68	64	48	29	32	31
New to the international market	36	17	28	15	8	18
Innovative Non-Productive Processes	218	178	114	100	100	100
New to the firm	128	121	65	59	68	57
New to the local market	62	46	37	28	26	32
New to the international market	28	11	12	13	6	11

Source: Own calculations based on data from the Innovation Surveys 1998-00; 2001-03 and 2004-06, ANII/DiCyT/INE.

[3] The reported differences are all statistically tested for (taking into account the estimated means and variances). The output is available upon request.

A last relevant characterisation of ‘surviving’ innovative firms, that is also shared by other types of innovators, relates to the composition of their total innovation expenditure by type of input. The share of companies that invest in training programmes, physical capital and ICT tools is extremely high and stable along the economic cycle. They are at least 20pp larger than the percentages associated to those that acquire knowledge-driven inputs *par excellence* – R&D and DTC – while the gap further increases in 2006 even though the share of innovators that fully diversify their investment goes up in 20% (Table 3). Such low propensity to invest in R&D is of particular concern, especially when put in context with the scarce average degrees of novelty that are attained.

Table 3. Distribution of innovative firms by innovation input 1998-2006

	2000	2003 (number)	2006	2000	2003 (%)	2006
Innovative firms	294	240	221	100	100	100
R&D	164	135	103	56	56	47
Physical Capital+Hardware+Software	256	195	182	87	81	82
Training Programmes	205	170	157	70	71	71
Engin. & Ind.Design+Tech.Trans+Cons.Svs.	127	107	84	43	45	38
Only one input	75	60	41	26	25	19
All inputs	60	48	54	20	20	24

Source: Own calculations based on data from the Innovation Surveys 1998-00; 2001-03 and 2004-06, ANII/DiCyT/INE.

The regularities above discussed strongly suggest that the empirical modelling of the innovative behaviour of firms must acknowledge for the observed heterogeneity in the composition of the total innovation expenditure as well as in both the type and novelty degree of the innovation output generated. We therefore define in the following sub-section a set of indicators that suit the purpose.

4.3. Diversification of innovation investments and innovation output indicators

In order to reflect the eventual impact on innovation activities of a more/less diversified investment across inputs, we calculate a Herfindahl-type index for each wave of the IS - the ‘Innovation Input Concentration Indicator’ (IICI).

We define the weights in terms of the percentage expenditure devoted to each input. Hence the IICI goes down to zero the more diversified the total investment is and it is equal to ‘1’ whenever the firm invests in only one input.

We also build an indicator to proxy innovation output values for each firm that is able to account for both the number of innovations achieved and their degree of novelty. Following the methodology proposed in Cassoni and Ramada-Sarasola (2012), we first generate individual indices for each type of output and afterwards add them up in an Overall Innovation Output Indicator– OIOI.

The individual indices are a weighted average of innovations of a particular type with distinct novelty degrees. We define the weights as the inverse of the relative frequency of innovators that generate an output new to the firm/the local market/the world and calculate them controlling for sample design effects for each wave of the IS using all sample units (not just those included in our sub-sample). The OIOI ranges from 1 to ∞ for innovative firms and is equal to 0 for non-innovators.

The descriptive statistics in Table 4 show that firms that innovate in both products and processes have a relatively more diversified investment than the rest and that its temporal evolution is scarcely linked to the economic cycle. Only-product-innovators seem to have progressively diversified their expenditure while those specialised in processes seem to go in the opposite direction since 2003.

Table 4. Innovation Input Concentration Indicator – Descriptive statistics 1998-2006

IICI	1998-2000		2001-2003		2004-2006	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
All innovators	0.60	0.34	0.60	0.33	0.67	0.30
Product and processes innovators	0.53	0.32	0.55	0.31	0.56	0.29
Only product innovators	0.89	0.21	0.72	0.36	0.80	0.28
Only process innovators	0.67	0.35	0.66	0.35	0.75	0.29

Source: Own calculations based on data from the Innovation Surveys 1998-00; 2001-03 and 2004-06, ANII/DiCyT/INE.

The average value of innovations remained unchanged until 2003 but decreased sharply, and up to a similar extent for products and processes, in 2006 (files 1 to 3 in Table 5).[4] The OIOIs vary within significantly wider ranges in 2003 than otherwise, a fact that reflects that the strategies used by innovators to sort out negative shocks are much more diverse compared to those displayed at other stages of the cycle.[5]

Table 5. Innovation Output Indicators – Descriptive statistics 1998-2006

	1998-2000		2001-2003		2004-2006	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Innovative Products Indicator	10.0	6.7	10.4	11.0	7.6	5.1
Innovative Processes Indicator	6.7	6.1	7.0	9.1	5.1	5.3
Overall Innovation Output Indicator	8.3	7.0	8.9	9.8	6.3	5.7
Only product innovators	3.1	1.4	3.4	2.1	2.9	0.6
Only process innovators	5.0	5.1	5.8	7.4	3.7	3.2
Product & processes innovators	10.7	7.2	11.0	10.7	9.4	6.5

Source: Own calculations based on data from the Innovation Surveys 1998-00; 2001-03 and 2004-06, ANII/DiCyT/INE.

Whenever all innovators are considered, the mean value of novel products is always above that of new processes. However, the opposite holds if only firms that innovate in a sole type of output are taken into account instead (files 4 and 5 in Table 5). The temporal paths followed by the indicators are also distinct within these subsets: while the value of new products is stable along the cycle, that of new processes evolves slightly counter-cyclically.

On the other hand, the largest average value of innovations is systematically observed across firms that innovate in both products and processes and its evolution in time is analogous to that characterising all innovators (bottom file in Table 5). At the other end, the least relevant innovations are generated by firms that innovate only in one type of output.

These behavioural patterns suggest that there are complementary effects linked to the joint

[4] See footnote 3.

[5] The coefficients of variation of the OIOIs in 2003 relative to 2000 and 2006 are 25% to 50% larger depending on the year and type of innovator.

production of novel products and processes. Given that these innovators are those that most diversify their investment, the enlarged value of innovations may be rooted on their use of a comparatively more suitable production technology. The reliability of the hypothesis can be hence explored by means of the inclusion of the IICI in the KPF.

The above regularities are consistent with the evidence reported in Cassoni and Ramada-Sarasola (2012) for the whole sample. Consequently, they are not specific to medium and large 'surviving' innovators but also common to small innovative firms and to those that left and entered the market.

5. The innovative behaviour of firms along the cycle

5.1. The empirical CDM model for Uruguay

We specify the first two equations of the CDM model as a Generalised Tobit mirroring the setting proposed in Crépon *et al.* (1998) reproduced in Equations (1) and (2) in Section 2 and defining the innovation intensity as the financial effort devoted to innovation in terms of the actual and not the expected availability of monetary resources. Thus, our proxy measure for the innovation effort is the ratio of total innovation expenditure to the lagged level of sales.[6]

We specify the KPF as a dynamic function of the stock of innovative inputs. Given that their pre-existent endowment is embedded in the innovation output generated in the past, the equation may be stated in terms of the current innovation investment and the lagged value of the innovation output.[7] The lack of data on past innovations is sorted out by expressing them as a share of the lagged stock of knowledge-capital that can in turn be substituted by a function of the lagged levels of productivity, employment, capital to labour ratio and raw materials using Equation (4) in Section 2.

The innovation investment cannot be considered exogeneous to the KPF since the impact of unexpected shocks on both processes are theoretically related. It is thus instrumented using the predicted values of the financial effort devoted to innovation from Equation (2) and the lagged value of sales. Equation (3) is hence re-stated, omitting for simplicity the sub-indices *i* and *t*, as:

$$\Delta KC = A(k^{e})^{a} * (C/L)_{-1}{}^{b} * (RM)_{-1}{}^{c} * (Y/L)_{-1}{}^{d} * L)_{-1} * S_{-1} * \exp(\boldsymbol{X}_{3i}\boldsymbol{\beta}_{3}) \qquad (3')$$

We specify equation (3') in logs as a Tobit model using the OIOI as a proxy for ΔKC. We estimate the model only for the subset of innovative firms.

Under the assumption that the accumulated stock of knowledge-capital at a given point in time gives rise to a new production possibility frontier in terms of employment, physical capital and raw materials, the beginning-of-period stock is equivalent to a function of the observed mix of these three production factors in the previous period and their associated output. The overall production function in a specific time-period may be thus defined as a dynamic function of raw materials, physical capital

[6] We discarded the use of the total innovation expenditure *per* worker as a measure for the innovation intensity due to its implying that the factor intensity is homogeneous across firms, an assumption that is not suitable in the Uruguayan case.

[7] It has to be noted that the parameter associated to the lagged innovation output within the new specification is a function of the inertia inherent to the production technology of innovations and also of the input-output elasticity.

and labour that further interacts with the innovation output generated during that term. Given the definition of the OIOI, we postulate that it enters the production function of innovative firms exponentially.

The innovation output cannot be assumed to be exogenous to the overall production function and is therefore instrumented, as before, using its predicted values from the KPF and assigning a zero to non-innovators. The resulting labour productivity equation is specified in logs, omitting the sub-index *i* for simplicity, as:

$$\ln(Y/L)_t = \sigma_1 \Delta KC^e_t + \lambda_1 \ln(C/L)_t + \lambda_2 \ln L_t + \lambda_3 \ln RM_t + \mu_1 \ln(C/L)_{t-1} + \mu_2 \ln L_{t-1} + \mu_3 \ln RM_{t-1} + \theta \ln(Y/L)_{t-1} + \boldsymbol{X}_{4i}\boldsymbol{\beta}_4 \qquad (4')$$

All four equations include individual effects that are assumed correlated with the disturbance; binary variables that account for the firm's economic sector; a market concentration index calculated as the share of the four biggest firms in the sector's total sales value; and an indicator of the stage of the business cycle defined as the 3-year average growth rate of gross domestic product centred in the current year.[8]

Firm characteristics influencing the propensity to innovate relate to: (i) technological features of the firm that prevailed prior to the 3-year span for which the IS's information is referred, as embedded in the lagged levels of physical capital to labour ratio and labour productivity (in 2006-pesos)[9]; (ii) specific-to-research-activities characteristics assumed to be reflected on the share of engineers in the staff of professionals (percentages) and on the existence of a formal R&D unit at the beginning of the 3-year period (binary variable); (iii) structural dimensions that may ease the firm's access to both information and financial resources, as measured by the scale of the firm; its belonging or not to an economic group and its national/foreign ownership, distinguishing between firms partially and fully-owned by foreign entrepreneurs (binary indicators); (iv) its main sales market as a measure of the degree of competitiveness faced, differentiating firms that are fully local-oriented from those that are partial or full exporters (binary variables); (v) the relevance – high/low - assigned to getting access to information from diverse sources - NSI agents, clients, related firms, consultants, universities, journals, conferences or fairs – (binary variables); and (vi) the extent – largely/scarcely – to which engaging and/or developing innovation activities have been hampered by diverse obstacles (binary variables) that stem from the firm (linked to the workforce skill-level, organisational efficiency, risk-aversion and the innovation investment time-horizon); the market (related to market size, access to financial-aid, cooperation and ease of imitation); or the macroeconomic framework (in terms of the access to information, infrastructure, public policies and property rights systems).

The same variables, with the exception of those listed as (v) and (vi), are included in the innovation intensity equation. We further add a binary variable that accounts for the availability or not of external financial-aid as well as the percentage share of external resources in total expenditure differentiated by

[8] The definition of the variables and some descriptive statistics are summarised in the Appendix (Tables A1 and A2).
[9] We deflate monetary values using price indexes defined at the 2-digit ISIC sector level so as to express them in 2006-pesos.

source (internal to the firm, related agents, the banking system, the government and international institutions). In order to explore the eventual impact of the input composition of the innovation investment, we include binary variables that state if resources have been devoted or not to the acquisition of each of the defined types of input. These variables further serve to control for the effect of relative prices. We also account for the degree of concentration/diversification of total investment through the inclusion of the above-defined indicator – IICI.

Control factors included in the KPF are those in (i) to (iv); the set of binary variables associated to the type of input that are intended to reflect eventually differentiated scale effects; the IICI as a measure of an efficiency-related impact originated in the input mix chosen; the current existence or not of a formal R&D division; and the existence or not of linkages with NSI agents that are assumed to generate positive externalities that increase the odds of success (they are differentiated by the goal sought - training programmes; technical assistance; general information; and R&D-oriented information.

Lastly, firm-level control variables included in the dynamic labour productivity equation relate to its membership to an economic group, national ownership and main sales market.

5.2. Empirical results and discussion

Each equation of the recursive model is estimated using Full-Maximum Likelihood methods in order to allow for firm individual effects to be correlated to the disturbances. The estimation results show that the self-selection of firms as innovative has to be accounted for in order to avoid biased estimates of the parameters in the intensity equation. The degree of market concentration does not exert an impact on any stage of the innovation decision-process while unobservable heterogeneity across economic sectors is scarcely relevant (Table A3 in the Appendix). [10]

4.2.1. Propensity and intensity of innovation

In line with the reported evidence, the largest firms are the most prone to innovate and least intense innovators. However, in contrast to some previously suggested patterns, no differences stem from their membership to an economic group and/or their national ownership while the innovation propensity is unaffected by labour productivity levels and/or the factor-intensity of the technology prior to innovation. Nevertheless, a highly productive workforce, particularly among labour-intensive firms, would allow those that do engage in innovation to devote a smaller effort to the activity (Table 6).

Features directly linked to the production of innovations (the pre-existence of a formal R&D unit and/or a large share of engineers in the professional staff) and the firm’s partial/full participation in international markets act as drivers of knowledge accumulation practices. Yet, they have no impact on the intensity of the financial effort. However, the composition of total expenditure by input type does differentiate firms according to the degree of intensity, the largest magnitude being observed among

[10] The reported evidence is based on testing diverse hypotheses with a confidence level equal to at least 90%.

those with the least diversified expenditure and/or that invest in novel physical capital. The smallest effort is in turn registered for firms that invest in training programmes.

Table 6. Estimated coefficients – Innovation propensity and intensity

Variables	Propensity Marg.effects	Intensity (log) Innov.expend./sales(-1)
Size: 20-49 workers ¥	0.74***	-0.63*
Size: 50-149 workers ¥	0.91***	-0.68*
Size: 150 workers & more ¥	1.24***	-0.96**
Engineers/professionals (%)	0.93***	0.01
Formal R&D unit - 1 lag ¥	0.37***	-0.04
Exporter ¥	0.19*	0.43
Capital/Labour - 1 lag (log)	0.07	0.12**
GVP/Labour - 1 lag (log)	0.09	-0.52***
Obstacles – innovation associated risk ¥	-0.28*	---------
Obstacles – innovation investment-horizon ¥	-0.19*	---------
Obstacles – poor Science &Tech.-related institutions ¥	0.36*	---------
High-relevance information sources	0.79***	---------
External financial-aid ¥	---------	0.66**
R&D ¥	---------	0.73***
Eng.& ind. design+Tech.transfers+Consult.svs. ¥	---------	0.68***
Training programs ¥	---------	0.40***
Physical capital+hardware+software ¥	---------	1.69***
IICI	---------	1.38***
Business cycle	-4.28***	5.20**

Note: '¥' states the variable is binary. The reported coefficient is thus the marginal effect of a discrete change from 0 to 1. Sectoral dummies are omitted from the Table for the sake of simplicity.

Risk-aversion is the strongest deterrence of innovation while firms that consider the major barriers stem from the lack of highly developed science and technology institutions are in fact the most prone to innovate. The availability of external financial-aid is found to effectively increase the innovation intensity regardless of the specific source. Lastly, while the innovation intensity is procyclical, as expected, the propensity to innovate is counter-cyclical, in line with the previously described stylised facts.

Our findings suggest that the degree of innovativity is largely dependent on the firm's profile for developing innovation technologies and on its capability to face investment risks, particularly when subject to adverse macroeconomic conditions. Firms that diversify their investment and with specific technological profiles would need to devote a comparatively smaller effort to knowledge-accumulation activities, its magnitude further evolving in parallel to the overall economic trends.

4.2.2. The knowledge production function

According to the estimated KPF, a 10% increase in the innovation expenditure, *caeteris paribus*, would raise the innovation output in 2%. The elasticity is therefore quite below the values reported in the international literature (e.g., compared to the 0.5 calculated for Germany and Sweden by Janz *et* *al.*, 2003).[11] However, the impact of the overall expenditure would be magnified whenever investment is sufficiently diversified across inputs, as reflected in the estimated negative coefficient of the IICI. Given the scale effects identified, spending a share of total expenditure in R&D and/or training programmes would have an analogous effect. Once these three features are acknowledged for, the actual rise in innovations driven by a 1% increase in the innovation intensity associated to R&D or training-related investment would be at least doubled (Table 7).

Table 7. Estimated coefficients – KPF

Variables	KPF (log) OIOI
Intensity of innovation-predicted values (log)	0.20*
Exporter ¥	0.19***
Engineers/professionals (%)	0.17*
Formal R&D unit ¥	0.14**
Link w/NSI agents- General information	0.19***
Link w/NSI agents- Information on R&D	0.15**
R&D ¥	0.17*
Eng.& ind. design+Tech.transfers+Consult.svs. ¥	-0.02
Training programs ¥	0.21***
Physical capital+hardware+software ¥	-0.02
IICI	-0.33*
Business cycle	-4.85***

Note: binary variables are identified by '¥' and their coefficients are thus marginal effects.

Size, national ownership and membership to economic networks are not differentiating factors in terms of the relevance of innovations, neither is the prevailing production technology, that is here thought of as a substitute measure for the beginning-of-period knowledge-capital stock (see Table A3 in the Appendix). In contrast, the participation in international markets and features directly related to innovation are mirrored in an enlarged value of innovations. No differences are in turn associated to the firm approaching or not NSI agents but once a link has been established, those that seek for information on both general issues and R&D are able to attain innovations of a higher relevance.

Therefore, differences in novel outputs in time and across firms are suggested to be linked to the innovation practices undertaken during the current 3-year span to a larger extent than to their prior innovative behaviour, consistent with the previously discussed descriptive patterns. The degree of success of innovators is also found to largely depend on the technical profile of innovation and on the firm main sales market. However, its counter-cyclical evolution suggests that the increased propensity to innovate during downturns involves innovators that develop new outputs of enhanced value.

4.2.3. The labour productivity model

Except for the positive effect associated to firms' membership to an economic group, none of the control variables included in the productivity equation is statistically significant (see Table A4 in the Appendix). The parameters characterising the dynamic production function imply that firms in this

[11] See the review by Hall and Mairesse (2006) and references therein.

subset use a technology that exhibits increasing returns to scale (the long-run product elasticities are 0.05 and 1.11 for physical capital and labour, respectively). The long-run product elasticity with respect to innovations evaluated at the mean value of OIOI (7.88) is 0.05, implying that an innovation valued twice the observed average (as measured by the normalised indicator OIOI) would result in a 5% increase in labour productivity levels (Table 8). [12]

Table 8. Product-elasticities

	Elasticities	
Variables	Short-run	Long-run
Physical capital	0.0225	0.0483
Labour	0.5043	1.0847
Raw materials	0.3924	0.8442
Innovation output*/	0.0236	0.0507

Note: */ Calculated at the mean value of OIOI (7.88).

The estimated elasticity is quite low compared to, e.g., the 0.13 reported for Flanders in Van Leeuwen and Klomp (2006) or the 0.1 estimated in the original CDM paper for France. The gap is however not necessarily due to differences in the returns to innovation activities. It may instead stem from the substantially lower average novelty degree attained in Uruguay that is partially linked to the type of innovations sought by firms. Indeed, the parameter would be in line with the international findings (0.11) if calculated for the top 25% of the OIOI values while the estimated effects calculated for specific subsets of innovators are most heterogeneous, as it is readily seen in Table 9.

Whenever innovation involves products and processes (as is the case in most developed countries), the increase in labour productivity at the mean value of the corresponding OIOI (10.5) is at least twice that associated to firms that only innovate in processes. If the elasticity is calculated at the mean of OIOI within the top 50% of these innovators (14.7), its value is quite consistent with the reported evidence for developed countries (0.09).

Table 9. Product-elasticities of innovations by type of innovator

OIOI	Mean value	Long-run elasticity
All innovators	7.9	0.051
Only process innovators	4.8	0.031
Product & process innovators	10.5	0.068
Product and productive process innovators	10.8	0.070

The empirical evidence for Uruguay to date that is strictly comparable to ours is that reported in Cassoni and Ramada-Sarasola (2012) using 2006 data, in which the estimated long-run elasticity is five times the value calculated at the mean of OIOI in 2006 according to our model. The divergence,

[12] The estimated coefficient multiplying OIOI in the labour productivity is 0.003 while that associated to the lagged value of labour productivity is 0.535 (see Table A4 in the Appendix).

that is partially due to the significantly reduced novelty and innovativity predicted at the bottom of the business cycle, is far from questioning the robustness of our evidence, as revealed by the figures obtained once having acknowledged for the characteristics of the samples. The comparison of other results from the two modes brings forth new and most enlightening insights.

First, given that 40% of large units in 2006 that are included in the dataset used in Cassoni and Ramada-Sarasola (2012) do not belong to our sample, the divergent patterns reveal the differentiated innovative behaviour of new and long-dated large companies. Since our findings reflect the behaviour of medium and large firms, the results suggest that the returns to innovation are higher for small than large companies.

In order to explore the likelihood of the hypotheses, we estimate the model specified in Cassoni and Ramada-Sarasola (2012) for the whole 2006 sample and also for three sub-samples. A first subset includes only mandatory inclusion units, regardless of them being included or not in the two previous surveys. A second subset is built with observations on firms that are surveyed in the three waves of the IS without taking into account their status within the sample (random or certainty units) while a final sub-sample involves firms of mandatory inclusion that survive all along the 10-year period. The results obtained strongly support the above argumentation and further allow for the identification of the specific underlying sources (Table 10).[13]

Table 10. Output elasticity of innovation in 2006 – comparison of estimates over different samples

Firms included	OIOI[1/] Mean	OIOI Coefficient	Inertia	OIOI Coefficient Long-run	Elasticity[2/] Short-run	Elasticity[2/] Long-run
All firms	5.0119	0.0086	0.2417	0.0358	0.0433	0.1793
Survivors	5.0400	0.0125	0.1522	0.0821	0.0630	0.4136
Certainty units	6.1243	0.0052	0.3298	0.0157	0.0316	0.0959
Survivors Certainty units	6.2455	0.0049	0.3555	0.0137	0.0305	0.0857

Notes[1/] Calculated controlling for sample design. [2/] Evaluated at the weighted mean value of OIOI.

Differences in the mean of OIOI are only linked to firm size, small companies generating innovations of lower relevance on average partially due to their increased propensity to innovate just in processes. However, the marginal impact on productivity (as measured by the OIOI coefficient) is substantially stronger for small relative to large firms, particularly among those that have been borne before 1998 and survived at least up to 2006. The magnitude of the effect in this case is such that it counter-balances the lower average value of innovations. These gaps are further enlarged in the long run due to the differentiated inertia inherent to the dynamics of labour productivity within the diverse subsets of firms, the most long-lasting effects being observed for small companies included in the three samples.

Taken together, the above results suggest that the significant productivity gains driven by knowledge accumulation are one most relevant means for firms to successfully perform along the

[13] Results are available upon request.

cycle, its key role being more crucial for small relative to large companies. These increased returns to innovation are likely to be partially rooted in the decreasing returns of scale that characterise the production technology of small enterprises.

According to the overall evidence obtained, the decision-process underlying knowledge accumulation is quite homogeneous across firms, differentiated patterns being identified at particular stages and only linked to firms' size and their main sales market. In line with the enhanced competition faced, the enlarged innovativeness of exporters is matched to their innovations being of a higher value than those produced by local-oriented firms, even though they devote a similar financial effort to the activity. Larger firms, in turn, are found to be more prone to engage in innovation activities and less intense innovators but in contrast to the generalised belief, once having accounted for the production technology used, they do not attain a novel output of increased relevance compared to that of small companies.

The technology of innovation plays a key role in terms of both the value of the novel output attained and the financial effort needed. Human resources and R&D activities are signalled at as the key innovation inputs at all stages of the process. An enhanced innovativeness, a reduced financial effort and an increased output value would be observed in firms that invest in R&D and get access to relevant information on the matter, particularly when they have a formal R&D unit. A further key requirement refers to disposing of a highly productive pre-existent workforce and of a professional staff with the adequate profile, as well as to investing in training programmes for employees and managers. The results strongly suggest that the feasibility of attaining high relevance innovations at the lowest cost is tightly linked to the input mix chosen and that it increases with the degree of diversification of investment.

Once the procyclical character of labour productivity and the increased scale associated to corporate firms are controlled for, we find that there are significant returns to innovation activities. The magnitude of the impact varies by firm size and depending on the type of output. The largest gains are found among companies that innovate in both products and processes, suggesting the two types of innovation complement each other, and they also increase with firm-size.

5. Conclusions

Our findings provide with most relevant insights on the mechanisms underlying knowledge accumulation practices in Uruguay that have been relatively disregarded up to now. As a consequence, policy recommendations that stem from them are of a quite distinct nature.

One key conclusion relates to the use of a sub-optimal production technology to generate innovations being a major hindrance for Uruguayan innovators that is suggested to act as a more stringent barrier than those posed by a scarce financial effort, an excessively far-away investment-horizon, a difficult access to external financial-aid and/or market and macro-related obstacles.

Therefore, a clear-cut recommendation for policy design relates to its setting the focus on the provision of technical assistance to firms. Such goal inevitably encompasses the creation of fluid information channels that should be extensively publicised in order to effectively promote the establishment of linkages between entrepreneurs and knowledge-related actors.

A major contribution of our research relates to the understanding of the dynamics of knowledge accumulation along the cycle. We provide with sound evidence on innovation activities being one generalised practice that allows firms for counteracting negative macroeconomic shocks, particularly through the introduction of novel procedures that are of a higher degree of novelty than those observed during the economic upswing. Most worthy lessons on the adequate means to sort out adverse shocks may result from a more in-depth analysis of innovation practices at the bottom of the economic cycle.

Further research needs to be devoted to the analysis of the innovation practices undertaken by small firms given that they are generally unable to attain high relevance innovations and yet get the largest benefits from knowledge accumulation. Since the vast majority of productive units in Uruguay are small-sized, the task stands as one of paramount importance.

The number of insufficiently explored dimensions is still large and is not exclusive to Uruguay. The dynamics of knowledge accumulation is one key feature suggested by our research that may involve two distinct phenomena that would be mirrored in the size of the associated productivity gains: the role of persistence linked to a learning-by-doing process and the eventual existence of an unavoidable (and/or optimal) temporal sequence in terms of types of novel output sought. A last topic that needs to be analysed in the future relates to the role of innovation activities on the odds of survival and of the externalities that might be driven by the entrance of new firms into the market.

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Appendix

Table A1. Definition and sources of variables

Foreign capital participation	% - IS
Engineers/professional staff	% - IS
Physical capital to labour	End-of-period capital stock (2006 pesos) over total workers - EAS
Labour productivity	Gross production value (2006 pesos) over total workers - EAS
Raw materials	Intermediate consumption (2006 pesos) - EAS
Labour	Number of employees - EAS
Financing: related agents	% - IS
Financing: public sector	% - IS
Financing: banking system	% - IS
Financing: international	% - IS
Innov. intensity	% - Inn.expenditure (2006 pesos) over lagged sales (2006 pesos) - IS
Sales	Monetary value in 2006 pesos - IS
IICI	Innovation Inputs Concentration Index – built using IS information
OIOI	Overall Innovation Output Indicator – built using IS information
Binary variables IS: 1 = Yes; 0 = No	
Innovative	Innovation expenditure>0 -
Size strata (4 variables)	5-19; 20-49; 50-149; 150 & more workers
Economic group	Firm is a member of an economic group or network
Full-foreign ownership	Multinational
Exporter	Main sales market is not local
Full-exporter	No local market sales
Pre-existent/current R&D unit	A R&D unit at the firm in the previous/current IS wave
High-relevance information	Information obtained on innovation was essential
Obstacles: skill-level	Lack of qualified workforce
Obstacles: rigidity	Organisational rigidities
Obstacles: associated risk	Innovation activities considered too risky
Obstacles: innovation horizon	Expected innovation investment time-horizon excessively long
Obstacles: technology	Scarce technological opportunities at the market-level
Obstacles: financial-aid	Insufficient access to external financial-aid
Obstacles: cooperation	Inexistent or insufficient links with other firms and/or institutions
Obstacles: property-rights	Under-developed systems
Obstacles: technical info.	Insufficient availability and/or access to technology-related info.
Obstacles: institutions	Science & Technology-related institutions are poorly developed
Obstacles: market info.	Insufficient availability and/or access to market-related info.
Obstacles: public policies	Poor and/or inadequate public policies related to innovation activities
Financial-aid	External-to-firm agents provide with financial-aid for innovation
Investment in R&D	R&D expenditure>0
Investment in DTC	Engineering & Ind. design/Tech.transfers/Consultancy expenditure>0
Investment in KHS	Novel physical capital/hardware/software expenditure>0
Investment in TP	Novel training programmes expenditure>0
Link with NSI agents	Link exists
Link: TA	Link with NSI seeking for technical assistance in general
Link: R&D	Link with NSI seeking for assistance on R&D
Link: TP	Link with NSI seeking for assistance on training programmes
Link: Information	Link with NSI seeking for general information

Notes: IS refers to Innovation surveys and EAS to Economic Activity surveys. Monetary values are expressed in 2006 pesos using the corresponding 2-digit ISIC price deflators

Table A2. Descriptive statistics

Binary variables	% Frequency (vble=1)			Binary variables	% Frequency (vble=1)		
All firms	2000	2003	2006	*All firms*	2000	2003	2006
Innovative firms	73	60	55	Sector: Food	28	28	28
Innovators	71	59	54	Sector: Beverages	3	3	3
Size: 5 to 19 workers	7	10	9	Sector: Tobacco	0.5	0.5	0.5
Size: 20 to 49 workers	29	36	27	Sector: Textiles	18	18	18
Size: 50 to 149 workers	42	35	39	Sector: Wood	3	3	3
Size: 150 workers & more	22	19	25	Sector: Paper	8	8	8
Economic group	20	18	21	Sector: Chemicals	16	16	16
Partial foreign-ownership	6	6	5	Sector: Oil & derivatives	0.2	0.2	0.2
Full foreign-ownership	9	10	13	Sector: Plastic products	4	4	4
Exporter	59	56	57	Sector: Non-met. minerals	3	3	3
Full-exporter	1	2	2	Sector: Basic metals	1	1	1
High-relevance information	63	85	77	Sector: Metallic products	13	13	13
R&D formal unit (lagged)	27	31	21	Sector: Other	2	2	2
Obstacles: skill-level	7	10	20	*Only innovative firms*	2000	2003	2006
Obstacles: rigidity	5	7	13	External financial-aid	48	40	32
Obstacles: associated risk	13	16	17	Link with NSI agents	89	91	93
Obstacles: innov. horizon	26	32	32	Link: Technical assistance	74	76	77
Obstacles: technology	14	10	13	Link: R&D	18	20	18
Obstacles: financial-aid	33	29	24	Link: Training progs.	51	51	57
Obstacles: cooperation	14	12	15	General information	68	69	72
Obstacles: property-rights	4	2	4	Investment in R&D	56	56	47
Obstacles: technical info.	3	3	6	Investment in DTC	48	53	39
Obstacles: institutions	14	12	17	Investment in KHS	87	81	82
Obstacles: market info.	7	4	6	Investment in Training	70	71	71
Obstacles: public policies	18	17	20	R&D formal unit	34	35	34
Continuous variables	Mean			Continuous variables	Mean		
All firms	2000	2003	2006	*Only innovative firms*	2000	2003	2006
Market concentration (%)	31	37	33	Innovation intensity (log)	-3.9	-4.2	-4.0
Economic cycle	-0.015	-0.042	0.028	OIOI (log)	1.8	1.8	1.5
Labour productivity (log)	13.9	13.8	14.0	IICI	0.60	0.67	0.60
Raw materials (log)	17.7	17.5	17.8	Financing: own (%)	64	69	69,0
Capital/employment (log)	12.5	12.6	12.7	Financing: rel. agents (%)	14	17	17
Employment (log)	4.3	4.1	4.3	Financing: public (%)	2	1	1
Lag-productivity (log)	14.0	13.9	13.8	Financing: banks (%)	18	10	10
Lag- raw materials (log)	17.7	17.7	17.5	Financing: internat.(%)	1	2	2
Foreign-capital (%)	12	14	16				
Lag-employment (log)	4.3	4.3	4.1				
Engineers/Profes. (%)	24	18	26				

Source: Own calculations based on data from Innovation Surveys (1998-00; 2001-03, 2004-06); ANII/DiCyT/INE.

Table A3. Innovation Propensity, Innovation Intensity & KPF – estimated coefficients

Innovation propensity	Marg. effect	Innovation intensity: Innovation expenditure/ lag- sales (log)	Coeff.	Innovation output: OIOI (log)	Coeff.
Size: 20 to 49 workers	0.91***	Size: 20 to 49 workers	-0.63*	Size: 20 to 49 workers	0.14
Size: 50 to 149 workers	0.91***	Size: 50 to 149 workers	-0.68*	Size: 50 to 149 workers	0.02
Size: 150 workers & more	1.24***	Size: 150 workers & more	-0.96**	Size: 150 workers & more	0.27
Economic group	-0.18	Economic group	0.13	Economic group	-0.05
Foreign-ownership (%)[1/]	-0.12	Foreign-ownership (%)	-0.55	Foreign-ownership (%)	-0.18
Full-foreign-ownership	0.05	Full-foreign-ownership	0.59	Full-foreign-ownership	0.30
Exporter	0.19*	Exporter	-0.21	Exporter	0.19***
Full-exporter	-0.52	Full-exporter	0.43	Full-exporter	-0.01
Engineers/Profs. staff (%)[1/]	0.93***	Engineers/Profs. Staff (%)	0.01	Engineers/Profs. Staff (%)	0.17*
Lag - R&D formal unit	0.37***	R&D formal unit (lagged)	-0.04	Lag - R&D formal unit	0.06
Lag- capital/employ. (log) [1/]	0.07	Lag - capital/employ. (log)	0.12**	Lag-capital/employ. (log)	0.01
Lag- productivity (log) [1/]	0.09	Lag - productivity (log)	-0.52***	Lag-productivity (log)	0.04
Obstacles: skill-level	-0.13	External financial-aid	0.66**	Lag-raw materials (log)	0.04
Obstacles: rigidity	-0.07	Financing: own resources	0.217	Link w/NSI	0.08
Obstacles: risk associated	-0.28*	Financing: related agents	-0.21	Link w/NSI: tech. assist.	-0.08
Obstacles: innov.horizon	-0.19*	Financing: public sector	-0.05	Link w/NSI: R&D	0.15**
Obstacles: technology	-0.09	Financing: banking system	0.02	Link w/NSI: training	-0.01
Obstacles: financial-aid	-0.12	Financing: intl. institutions	-0.19	Link w/NSI: general info.	0.19***
Obstacles: cooperation	0.03			R&D formal unit	0.14**
Obstacles: prop. rights	0.02	R&D	0.73***	R&D	0.17*
Obstacles: technical info.	-0.12	KHS	1.69***	KHS	-0.04
Obstacles: institutions	0.36*	TP	0.40***	TP	0.21***
Obstacles: market info.	0.25	DTS	0.67***	DTS	-0.03
Obstacles: public policies	-0.16	IICI	1.38***	IICI	-0.33*
High-relevance info.	0.79***	Inverse Mill's ratio	-0.85	Innovation intensity (log)	0.20*
Market concentration[1/] (%)	-0.06	Market concentration (%)	5.20	Market concentration (%)	-0.02
Economic cycle[1/]	-4.28***	Economic cycle	1.38**	Economic cycle	-4.76***
Std. Dev. residual	0.303	Std. Dev. residual	1.418	Std. Dev. residual	0.136
Rho	0.084*	Rho	0.008*	Rho	0.045**
Obs.	1113	Obs.	694	Obs.	710
Log likelihood	-547.7	Log likelihood	-1228	Log likelihood	-693.3

Notes: [1/] estimated coefficient. Equations also include sector dummies.

Table A4. Labour productivity equation – estimated coefficients

Labour productivity: GVP/employment (log)	Coefficient
Economic group	0.041***
Foreign-ownership (%)	0.024
Full-foreign-ownership	0.002
Exporter	0.006
Full-exporter	-0.025
Lag - raw materials (log)	-0.442***
Lag - Capital/employment (log)	-0.006
Lag - employment (log)	0.449***
Lag - productivity (log)	0.535***
Raw materials (log)	0.834***
Capital/employment (log)	0.022***
Employment (log)	-0.852***
Innovation output	0.003
Market concentration	0.005*
Economic cycle	0.481**
Obs.	1137
Chi2(27)	32732***

Note: The equation also includes sector dummies.