Innovation and Competition: evidence from Uruguayan firms.

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Abstract

This article investigates the relationship between product market competition and innovation. We find a negative and significant impact of competition on resources devoted to innovation activities, but a strong evidence of a positive and significant effect of competition on the efficiency of innovation expenditures using micro-level data from Uruguay. Moreover, we find that this effect is not negligible. An increase in one standard deviation (sd) in competition increases the efficiency in innovation expenditures between 1.0 sd and 2.5 sd depending on the measure of efficiency. Our finding has important implications for antitrust policy: as competition increases, resources devoted to innovation activities become more efficient.

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1.Introduction

The relationship between competition, innovation and productivity - commonly referred to as TFP - has been the subject of a broad debate since Adam Smith (1776). In this article, we devote our effort to understanding the channel through which competition affects innovation. Understanding this mechanism is not only a challenge in the academic ground but also, and essentially, a crucial issue for public policy. As we progress in understanding this relationship, it will be possible to design an economic and antitrust policy that favors the growth of innovation and productivity.

In this article, we estimate the effects of product market competition on the innovative activities performed by the firms. The estimation of this relation must deal with two main identification threats (i) unobserved heterogeneity, and (ii) reverse causality from innovation activities towards competition. We do so, using instrumental variables controlling for sector level fixed effects. Our chosen instrument is import penetration from China. We believe this is a valid instrument because (i) changes in import penetration from China reflect changes in the export performance from China rather than internal factors in Uruguay, and (ii) import penetration from China is correlated with the competitive environment in Uruguay.

We find no significant effect of competition on the number of innovations. We find, however, a negative effect of competition on innovation efforts as percentage of sales, but a positive and significant effect of competition on the efficiency of innovation expenditures. Moreover, this effect is not negligible. An increase in one standard deviation (sd) in the competition increases the efficiency in innovation expenditures between 1.0 sd and 2.50 sd (depending on the measure of efficiency).

We present a theoretical model that help to explain our empirical results. The model suggests that the effect of competition on innovation activities depends on the uncertainty about the relative asymmetry among firms. When a firm chooses its investment level on innovation, the firm does it without knowing if it will succeed or not. Moreover, it does that without knowing if their rivals are investing or not, and without either knows whether they will succeed or not. Our first empirical result suggests that for Uruguayan firms, on average, the expected positive effect on profits from innovative efforts is smaller when competition becomes more intense because competition punishes more the benefits when a laggard firm (a higher relative cost firm) gets the innovation than what awards, in such a case, a leader one (a lower relative cost firm). In others words, if a firm gets the innovation and becomes the market leader, as competition increases the expected benefits from innovation increase less than the decrease of benefits from innovation when competition increases in case of a laggard firm.

We consider that the probability of success depends on current innovation expenditure and on managerial efforts. Consequently, the positive effect of competition on the efficiency of innovation investment may be understood by thinking that as the competition increases, the decrease in innovation expenditure is compensated with a greater quality of managerial effort.

Thus, this fact would explain our empirical finding about the positive effect of competition on efficiency of innovation efforts.

To sum up, in average, for Uruguayan firms, the expected benefits from innovation tends to be reduced as competition intensity increases. Additionally, more competitive pressure, that reduces the firm's incentive to invest in cost-reduction innovation, forces them to manage this small investment in a more efficient way through a better quality of managerial effort.

We believe these findings and their interpretations consider two realistic characteristics on the firm's decision problem; namely, the potential differences among firms about their ability to carry out innovations, and the fact that decisions about innovation expenditure are taken under uncertainty. Up to our knowledge, they are novel elements in the literature that linking competition and innovation in developing countries. Moreover, we care about the efficiency of the innovation expenditure, and we find a significant and positive causal evidence between competition and efficiency of innovation investment.

Literature Review. There exists an extensive theoretical and empirical literature that discusses the effects of changes in competitive environment on the incentives to innovate, and to the adoption of new productive techniques. It should be noted, however, that there is no an accepted theory about how competition affects the innovative activities. A similar observation arises out from empirical research where that relationship also remains ambiguous. Literature on competition, and innovation is vast, so we only focus on the most closely related contributions. The issue on analysis has a long and controversial history that traces back to Schumpeter (1942), who emphasis that monopoly rents provide incentives for innovation and that perfect competition is not the most efficiency market structure to foster $R\&D$ activities. Arrow (1972) works on the polar view, and claims that competition imposes pressure on firms to carry out innovative efforts.

To find the source of this so opposite conclusion is useful to think that innovation incentives can be computed as the difference between the profits that a firm earn if it invests in innovation (ex-post profits) and the profits that it gets if it does not invest (ex-ante profits). The effect of competition on this definition of innovation depends on the notion of competition used, on the underlying oligopoly model, on the institutional framework of property right protection among other elements. In a broad sense, it is possible to think that an increase in competition tends to reduce individual firm profits in a symmetric firm context. Thus, in this framework, Schmutzler et al. (2010) points out that one reason for the ambiguous results may stem from the differential impact of competition on ex-ante and ex-post profits. While an increase in ex-ante competition (that reduces ex-ante profits) will increase the incentive to innovate, an increase in ex-post competition (that reduces ex-post profits) will reduce the incentive to innovate. Nonetheless, the relation between competition and innovation may result ambiguous when simultaneous changes in ex-ante and ex-post competition occur. Theoretical answers to this issue can be divided in two strands, namely research based

on partial equilibrium models (industrial organization and agency theory literature), and research based on general equilibrium model (endogenous growth literature). Leading models on the industrial organization that are closer to our theoretical framework are Dasgupta and Stiglitz (1980a) and Dasgupta and Stiglitz (1980b). Vives (2008) and Schmutzler (2013) using an unified two-stage framework identifies the circumstances under which more competition leads more innovative efforts. While Vives (2008) considers symmetric firms, we are close to Schmutzler (2013) in the sense that it is central to the interpretation of our results the distinctive effect of competition to more efficient firms respect to less efficient ones.[1]

Moreover, from the agency theory, many model discusses what happen when exist a separation of ownership and control.[2] In this strand of the literature, the closer contribution is Raith (2003), who finds a positive relationship between competition and efficiency gains because managers exert greater efforts in innovative activities. Raith (2003) shows that in equilibrium, where the number of competitors is determined endogenously, an increase in the competitive intensity leads to the implementation of better technologies and organizational practices.

From growth literature, Aghion et al. (1997) and Aghion et al. (2001) consider an oligopoly setting with asymmetric firms in an endogenous growth model. They find that increasing competition increases innovation expenditure when firms are symmetric, but they find a negative impact on innovation when firms are cost asymmetric.

Nonetheless, there are other factors that influence in the relation between competition and innovation. Holmes et al. (2012) conclude that a greater competitive intensity encourages the adoption of new and better productive techniques. Assuming that adoption of technologies entails significant short-term costs during the period of adaptation to new technologies, as competition increases these costs decrease since profits are small as competition increase.

Regarding the empirical literature, following Schumpeter (1942), a series of econometric studies have examined the relationship between the two variables. Scherer (1967) studies the relationship between competition and innovation using cross-sectional data for 500 companies in the US. His main finding is that the relationship between both variables has the shape of an U-inverted: for 'low' levels of rivalry, a greater competitive intensity encourages innovation; while the opposite occurs for 'high' levels of competition. The author does not, however, offer any qualitative explanation of these results. After then, other articles support the Schumpeterian hypothesis, confirming the existence of a negative relationship between competition and innovation. Among the most relevant are Blundell et al. (1999), Crépon et al. (1998), and Campante and Katz (2007).

Following the ideas of Scherer (1967), Aghion et al. (2005) examines the relationship between competition and innovation for a sample of 311 firms in the UK during the period 1973-1994. Using the price-cost margin to measure competitive intensity, and an index based on patent

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[1] In this regards, we are also close to Boone (2000).

[2] See for example, Martin (1993), Schmidt (1997), Bloom et al. (2015), Van Reenen (2011), and Cuñat and Guadalupe (2005) among others.

counting -weighted by the 'quality' of the patents - the authors confirm the findings of Scherer (1967). The most important conclusion is the existence of an optimal intermediate level of competitive intensity. Following Aghion et al. (2005), a series research[3] finds evidence of an inverted U-relationship between competition and innovation using data of different countries and regions. However, as Tingvall and Poldahl (2006) emphasize, these results depend on the measure of competition used. In particular, if the Herfindahl index is replaced by the price-cost margin index, the relationship between the two variables becomes negative. Moreover, a recent number of research papers question the findings of Aghion et al. (2005).[4] These all results are by no means conclusive. In principle, they only suggest the need for a greater number of empirical investigations. In this line, the empirical evidence linking innovation and competition to developing countries is scarce. However, there is an incipient set of studies that shed light on this matter. Most of the available analyzes focus on the effect that international competition has on innovation and especially on productivity in domestic markets.[5] Carlin et al. (2004), using survey data for 4000 manufacturing firms in 24 developing countries, finds an at least suggestive result: the effects of competition on innovation are positive and economically important only when the number of competitors goes from one to four or five. In other words, a minimum of rivalry is crucial to encourage innovative activities.

From this look around on the empirical literature, we find that most of empirical papers measure innovation activity by *R&D* expenditures, and by the number of innovations;[6] however, we also consider the efficiency of innovation expenditure. We find a positive effect of competition on that measure, and this result is robust to different competition measures. The paper is organized as follows. Section 2 describes the datasets we use in the paper. Section 3 presents the econometric model and the identification strategy. Section 4 shows the empirical results. In Section 5 we provide a theoretical context that helps to rationalize our findings. Finally, Section 6 concludes. All tables and figures are included in the appendix.

2.Data and Measurement issues

We use three sources of data to estimate the impact of competition on innovation activities in the Uruguayan manufacturing sector: the *Survey of Innovation Activities*, the *Survey of*

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[3]Polder and Veldhuizen (2012), Lee (2005), Peroni and Ferreira (2012), Tingvall and Poldahl (2006)

[4]Most significant is perhaps the work of Correa and Ornaghi (2014) for US manufacturing companies during the period 1974-2001. The authors, considering the structural changes in the patent policy that occurred during the period corresponding to the study of Aghion et al. (2005) find a strictly positive relationship between innovation and competition. Hashmi (2013) additionally confirms this positive relationship for manufacturing companies in the US. Using a methodology similar to that of Aghion et al. (2005), Boldrin et al. (2011) also finds a positive relationship between innovation and competition.

[5]Fernandes (2007) for Colombia, Amiti and Konings (2007) for Indonesia, Ferreira and Rossi (2003) for Brazil, and Bustos (2011) for Argentina.

[6]Empirical papers also consider patents as a measure of innovation.

Economic Activity, and *United Nations International Trade Statistics Database* (UN Comtrade data).

<center>*A.Survey of Innovation Activities*</center>

The Survey of Innovation Activities aimed at capturing innovation activity by firms and is carried out by the National Agency of Research and Innovation (ANII) in Uruguay. This survey collects information about innovation activity for a three-year period. We use four waves of this survey: 2004–2006, 2007–2009, 2010–2012 and 2013–2015. The population of interest are firms with more than five employees and the sample design uses stratified sampling (based on population and sales) with a panel structure. We restrict our sample to manufacturing firms with a positive number of employees and sales.[7] We use this survey to measure innovation outcomes, innovation efforts, efficiency in the innovation expenditures, organizational changes and firm's characteristics (size, age, and whether the firm belong to a holding company).

The final sample has 3,336 observations. The size distribution is similar to other Latin American counties with many small firms and a few large firms. In Uruguay, 50 percent of the firms have fewer than 36 employees but the largest 1 percent has more than 800 employees.

Innovation outcomes. The survey classifies an innovation in a product innovation (selling a new or significantly modified product), a process innovation (adoption of new or significantly improved processes aimed at improving product quality or reducing production costs), an organizational innovation (changes in the organization and organization design), and a marketing innovation (adoption of new marketing methods).

We used this information to create several variables to measure innovation outcomes. First, a dummy variable whether the firm introduced a technological innovation, i.e. a product or a process innovation (*Technological innovation* variable), and a dummy variable whether the firm introduced a non-technological innovation, i.e. an organizational or a marketing innovation (*Non-technological innovation* variable). Third, a dummy variable whether the firm introduced an innovation regardless of the type (*Any innovation* variables). Finally, a dummy variable whether the firm introduced a "new to the market" innovation (*Any innovation: new to the market* variables).[8]

We believe that these measures of innovation outcomes are more appropriate to capture innovation activity in Uruguay than other variables like patent counts. First, Uruguayan firms seldom applied for patents. For example, only 1 percent of the firms in the innovation survey 2007–2009 applied for a patent in the period. Second, innovation efforts in Latin American countries are more related to technology adoption through the acquisition of capital

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[7]We also drop the manufacturing sectors where there are less than 4 firms, on average, in the Survey of Economic Activity because we cannot compute competition accurately.

[8]This variable aims at capturing high-quality innovations.

goods rather than novel discoveries suitable for new patents.[9]

Table 1 reports descriptives statistics for innovation outcomes. 38 percent of the firms introduced a technological innovation, 20 percent introduced a non-technological innovation, 43 percent introduced an innovation, and 21 percent introduced a "new to the market" innovation.

Innovation efforts. The survey reports different sources of expenditures aimed at producing innovations: research and development (R&D), acquisition of capital goods, acquisition of information technology, technology transfer, industrial design, training, organizational design, and market research.

We aggregate these expenditures at different levels to measure innovation efforts: the ratio of R&D expenditure over sales (*R&D exp. over sales*), the ratio of R&D and capital expenditure over sales (*R&D and capital exp. over sales*), and the ratio of all expenditures on innovation activities over sales (*Exp. on innovation activities over sales*).

Table 1 reports descriptives statistics for innovation efforts. The average ratio of R&D expenditure over sales is 0.21 percent, the average ratio of R&D and capital expenditure over sales is 1.41 percent and the average ratio of expenditure on innovation activities over sales is 1.75 percent. These statistics illustrates that most of the innovation efforts are made through the acquisition of capital goods which justify using a more comprehensive measure of innovation efforts for Uruguay.[10]

Efficiency of innovation expenditure. We define efficiency of innovation expenditure as the ratio between an innovation outcome and expenditure on innovation activities (measured in millions of Uruguayan pesos of 2010).[11] To avoid working with a selected sample of firms with positive innovation expenditure, we compute this variable at the industry level (three-digit ISIC).

We construct several efficiency variables that vary on the measure of innovation outcomes. We use the following innovation outcomes in the sector: the number of innovators, the number of innovations,[12] and the number of "new to the market" innovations.

Table 1 reports descriptives statistics for efficiency of innovation expenditure. The average efficiency of innovations expenditure is 0.47 for the number of innovations, 0.77 for the number of innovations and 0.23 for the number for "new to the market" innovations. An efficiency of innovation expenditure of 0.77 for the number of innovations means that an investment of 50.000[13] dollars produces 0.77 innovations on average. If this variables increases then the

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[9]Gorodnichenko et al. (2010) present similar arguments to avoid using counts of patents as a measure of innovation for emerging countries.

[10]Rather than using only R&D expenditure which seems more appropriate for rich countries.

[11]20 Uruguayan pesos is approximately 1 dollar in 2010.

[12]We approximate the number of innovations summing up the process, product, organization and marketing innovations dummies for each firm.

[13]50.000 dollar $\simeq$ 1.000.000 Uruguayan pesos in 2010.

same expenditure produces more innovations hence efficiency increases.

Managerial practices. We also study if there is a relationship between competition and management practices. The Survey of Innovation Activities includes a set of 7 questions about management practices. Following Bloom and Van Reenen (2007), we group these practices (questions) into four areas: *operations*, *monitoring*, *targets* and *incentives*. Operations includes changes in organization design aimed at improving the operation of the firm like flattening the organizational structure. Monitoring includes activities aimed at improving monitoring and communication within the firm. Targets includes setting clear tasks and targets for each employee. Incentives includes using compensation mechanisms based on performance like incentive pay.

For each practice, we compute a z-score by normalizing to mean zero and standard deviation of one. The z-score gives less weight to the implementation of a minor practice (usually implemented by other firms) and more weight to the implementation of a more relevant practice (seldom implemented by other firms). Then we average the answers for each practice in the area and compute a z-score by area. Finally, we average the z-scores over areas and compute a z-score for overall managerial practice.[14]

Table 1 reports descriptives statistics for managerial practices. We can check that all variables have approximately mean zero and variance one as expected. Unfortunately the survey started collecting information on managerial practices only since 2007–2009 which explained the lower number of observations for these variables.

B.Survey of Economic Activity

The Survey of Economic Activity aimed at capturing economic activity and is carried out by National Bureau of Statistics. This is a yearly survey and we use the 2003–2012 surveys. We use this survey to measure the level of competition in the market. We believe that measuring the innovation activity and competition with different surveys alleviates the endogeneity of the competition variable, and helps in the identification of the causal effect of interest.

Competition. We measure competition using one minus the price-cost margin in the sector following Aghion et al. (2005).

We first approximate the price-cost margin of firm i at period t as

$$pcm_{it} = \frac{gross\,output_{it} - intermediate\,consumption_{it} - wage\,exp_{it}}{gross\,ouput_{it}}$$

where $gross\,output_{it}$ is gross output, $intermediate\,consumption_{it}$ is intermediate consumption, and $wage\,exp_{it}$ is wage expenditure for firm i at t. Then, we compute the weighted (by

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[14]Our procedure follows closely Bloom and Van Reenen (2007) and Bloom et al. (2012).

gross output) average price-cost margin across all firms in a three-digit ISIC industry j:

$$pcm_{jt} = \sum_{i=1}^{N_{jt}} w_{it}\, pcm_{it},$$

where $w_{it} = \frac{gross\ ouput_{it}}{\sum_{i=1}^{N_{jt}} gross\ ouput_{it}}.$[15] Finally, our measure of competition

is

$$competition_{jt} = 1 - pcm_{jt}.$$

An increase in $competition_{jt}$ signal an increase in competitive pressure in the sector. In the econometric model, we use lagged competition to avoid a feedback effect from innovation towards competition. For example, we use competition in 2003 and innovation in 2004–2006, and similar for other periods.

Table 1 reports descriptives statistics for competition. The mean value of competition is 0.82 with a s.d. of 0.09. The mean and s.d. of competition are similar to the ones reported in Correa and Ornaghi (2014) and Hashmi (2013) for the US.

C.UN Comtrade data

UN Comtrade collects bilateral trade exports and imports for over 180 countries. We use imports from China to Uruguay, and exports from Uruguay to compute import penetration from China.

Import penetration from China. We measure import penetration from China using the ratio between Chinese imports and apparent consumption (domestic production less exports plus imports) in sector j at t. Imports from China and exports from Uruguay come from Comtrade and domestic production come from the Survey of Economic Activity.

Table 1 reports descriptives statistics for import penetration from China. It has a mean of 0.07 and a s.d. of 0.10. However, these statistics hide a large variation across time and over sectors in import penetration from China. Table 2 shows that imports from China increase over time but this increase in concentrated in some sectors like textiles (17), apparel (18), television and communication equipment (32), bicycles and motorcycles (35), and games and toys (36).

3.Econometric Model and Estimation

The estimating equation for firm i in industry j at time t is

$$innovation_{ijt} = \beta\, competition_{jt-1} + \gamma' x_{ijt} + \eta_j + \eta_t + \epsilon_{ijt} \qquad (1)$$

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[15]We also use the sampling weights because of the stratified sampling in the survey.

where $innovation_{ijt}$ measures innovation activity for firm i in industry j at t, $competition_{jt-1}$ measures competition in industry j at $t-1$, x_{ijt} is a vector of controls at the firm level, η_j is an industry fixed effect, η_t is a time fixed effect, and ϵ_{ijt} is a time varying unobservable that affect the innovation activity for firm i at t.

The estimation of the causal effect of competition on innovation activity must deal with several identification concerns.

First, there could be unobserved heterogeneity at the industry level, and this unobserved heterogeneity could be correlated with both innovation activity and competition. If this is the case, a correlation between competition and innovation could be due to unobserved industry characteristics rather than a causal effect of competition on innovation. To deal with this problem, we include industry fixed effects that control for any time-invariant industry unobservable.

Second, both innovation activity and competition can be correlated with the business cycle. For example, if an expansionary cycle encourages more innovation activity and the entry of new competitors, we could estimate a positive correlation between innovation and competition even if there is no causal relationship between the two variables. To deal we this problem, we include time fixed effects that control for common trends that affect both competition and innovation in all sectors.

Third, there could be a reverse causality from innovation towards competition. For example, if a firm develops a successful innovation and gains market share then innovation activity will impact on its margins affecting our main measure of competition in the market. This reverse causality problem is the main difficulty to estimate the effect of competition on innovation. To deal with this problem, we use lagged competition rather than contemporaneous competition. Then, the timing decrease the likelihood of a reverse causality from innovation to competition. In addition, we use instrumental variables. A valid instrument must satisfy two conditions: (i) it must be correlated with the endogenous variable (*relevant condition*), and (ii) it must not be correlated with the error term (*exogeneity condition*).

Our instrument is *import penetration from China*. An increase in import penetration from China satisfies the *relevant condition* if an increase in Chinese imports in a market is (positively) correlated with a measure of competition in the market. Moreover, we expect an increase in Chinese imports in some sectors but not in other sectors and this variation will help identify the effect of competition on innovation even controlling for time fixed effects. As mentioned above, we find evidence that this is the case in Table 2.

The *exogeneity condition* requires that import penetration from China is not correlated with other unobservables that explain innovation activity. We believe that the instrument satisfy the exogeneity assumption because the increase in imports from China are part of a broader trend of an increasing participation of China in international markets rather that domestic factors in the Uruguayan economy. In addition, the main channel through which import penetration from China can affect innovation activity is competition. In fact, it is

difficult to find an alternative channel through which imports from China in a given sector affects innovation activity in the domestic firms in the sector.

4.Empirical Results

A.Instrument Validity

Table 3 reports the first stage regression between import penetration from China and competition. Column (1) includes industry fixed effects and column (2) includes firm's fixed effects. All models include time fixed effects and standard errors are clustered at the industry level.

The effect of import penetration from China on competition is positive and statistically significant. Moreover, the estimated coefficient has the expected sign: an increased in foreign competition from China increases the level of competition in the market. This is a quantitatively large effect: an increase in 10 percentage points in import penetration from China (around 1 s.d.) increases competition in 0.02 or 0.25 s.d.

To test for the relevance of the instrument we compute a (cluster) robust F-statistic. The robust F-statistic of 10.6 is significant at any relevant size. We also test for weak instruments. In the just identified case with one instrument, the robust F-statistic coincides with the effective F-statistic proposed by Montiel Olea and Pflueger (2013) to test for weak instruments with clustered errors. This test rejects the presence of weak instruments at a 5% level with a percentage of a "worst-case" bias of approximately 30%.

B.Main results

Table 4 reports the effect of competition on innovation outcomes. Each column estimates the effect on a different innovation outcome: the probability of introducing a technological innovation (process or product innovation), a non-technological innovation (organizational or marketing innovation), an innovation (process, product, organizational or marketing innovation), and a "new to the market" innovation (a proxy for a higher quality innovation).

We find that the effect of competition on innovation outcomes is not significant. The estimates are not very precise, but point estimates suggest that competition decreases technological innovations and increases non-technological ones.

Table 5 reports the effect of competition on innovation expenditures. Each column reports a different dependent variable. Column (1) uses R&D expenditure (internal and external R&D) over sales, column (2) uses R&D and capital acquisition expenditure over sales, and column (3) uses expenditure on innovation activities (includes both R&D and capital expenditure) over sales.

We find that competition has a negative and significant (at 5%) effect on R&D and capital acquisition expenditure and expenditure on innovation activities. On the other hand, there is

no effect on R&D expenditure.

There results deserve some comments. First, these results are consistent with the *Schumpeterian* argument that competition reduces the expected payoff from the innovation efforts, and thus the amount invested in innovation decreases in more competitive environments. Second, the results are mainly driven by decreasing expenditure on the acquisition of capital goods. This is expected because most of the innovation activity is emerging countries aims at the imitation or adaptation to existing technologies rather than the invention or discovery of new ones. Hence, the main innovation effort is made through the acquisition a new technology embodies in new machinery or equipment. Uruguay follows this pattern: capital expenditure is 80 percent of the expenditure in innovation activities. Finally, the fact the competition decreases innovation expenditure but not innovation outcomes suggests that firms might becoming more efficient at producing innovations. We explore this mechanism next.

Table 6 reports the effect of competition on the efficiency of innovation expenditures. We measure the efficiency of innovation expenditure using the ratio between the number of innovations and expenditure on innovation activities at the industry level. This variable measure the average number of innovations for each million Uruguayan $ in innovation expenditures.[16] When this variable increases, the same expenditure yields more innovations so efficiency of innovation expenditure increases.

Each column uses a different measure for the number of innovations in the numerator in the efficiency variable. Column (1) uses the number of innovators, column (2) uses the number of innovations, and column (3) uses the number of "new to the market" innovations.

We find that the effect of competition on efficiency of innovation expenditures is positive and significant. These results are robust for the different measures of efficiency. Moreover, these effects are not negligible. An increase in one s.d. in competition increases the efficiency of innovation expenditures between 1 sd and 2.5 sd depending on the specification.

We believe this is the most important result of the paper. Although previous papers studied the relationship between competition and innovation outcomes and expenditure, the efficiency of innovation expenditure has been neglected.

C.Competition and managerial practices

Recent literature find that competition raise productivity through management quality.[17] For example, Bloom et al. (2015), using data for English public hospitals, find that higher competition results in higher management quality and improved hospital performance.

Our results suggest that a similar mechanism could be at work: higher competition does not increase innovation expenditure, but it improves how well firms invest in innovation.

To study if this mechanism is present in our data, we estimate the relationship between

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[16]Around 50.000 dollars.

[17]Van Reenen (2011) reviews the empirical literature on this subject.

competition and management practices. We measure overall managerial practice and by areas (operations, monitoring, targets and incentives).

We estimate an OLS regression between competition and z-scores for managerial practices (overall and by area) controlling for industry dummies, time dummies and firm's controls.[18]

The main challenge to give a causal identification to our results is the possibility of reverse causality from changes in managerial practices at the firm level to competition at the industry level.

A reverse causality story should run as follows: a firm introduces better managerial practices and this increases firm's profits and margins. In turn firm's margins affect negatively our definition of competition. We believe that reserve causality should have a minor effect on our estimates. First, our measure of competition uses margins of all the firms in the industry. Then correlation between management practices and margins at the firm level should be mitigated at the industry level. Second, we uses the innovation survey to measure managerial practices, but we use the industry survey to measure competition. Given that the firms in both datasets are not all the same, this should also mitigate the correlation between managerial practices and competition. Fourth, our measure of competition is lagged one period. Then this timing should alleviate concerns about reverse causality. On the other hand, even if reverse causality is present in our data, the negative correlation between better managerial practices and competition should cause a negative bias in our estimates. Hence our estimates could be interpreted as lower bound to the causal effect between competition and managerial practices.

Table 7 reports the results of the relationship between competition and managerial practices. There is a positive and significant relationship between competition and overall managerial practices. This relationship is driven by changes in targets and, more importantly, change sin incentives. In other words, higher competition causes firms to implement or widen the use of compensation mechanisms based on performance and to redefine and clarify the tasks and targets for its employees. Bloom and Van Reenen (2007) find similar results for developed countries (United States, France, Germany, and United Kingdom) and Bloom et al. (2012) for transition countries. The main difference with our results is that both papers rely on cross-country variation for the same industry whereas we rely on variation over time for a given country.

5.Explaining our results

In Appendix B, we present the theoretical framework that allows us to analyze the relation between competition and innovation, and to provide some rationality to our empirical results.

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[18]We cannot estimate the instrumental variables model because the first innovation survey in 2004–2006 didn't asked these questions about managerial practices and without the first wave we cannot reject that our instrument is not relevant.

By considering firms as simply profit-maximizing agents, we study the transmission channels by which competition affects innovation. It is well-known that both theoretical and empirical literature show that those channels go into different directions. Therefore, given our empirical results, we use that theoretical context to explain how these transmission channels have operated in the Uruguayan industry between 2004–2015.

Effect of competition on innovation expenditure. From Uruguayan firms between 2004–2015, we meet the Schumpeterian argument; that is, as competition increases, it decreases the innovation expenditures. We rationalize this by taking into account that when a firm takes the innovation investment decision, it does it without knowing if it will succeed or not. Moreover, it does that without knowing if their rivals are investing or not, and without either knows whether their rivals will succeed or not. Our first empirical result suggests that for Uruguayan firms, on average, the expected positive effect on profits due to higher level of innovative efforts is smaller when competition becomes more intense. This might be because competition punishes more the benefits when a laggard firm (a higher relative cost firm) gets the innovation than what awards to a leader one (a lower relative cost firm) in such a case. In others words, if a firm gets the innovation and becomes the market leader, as competition increases the expected benefits from innovation increase less than the decrease of benefits from innovation when competition increases and the firm would get a laggard position in the market. Therefore, a risk neutral firm would reduce innovation expenditures as competition increases. It is quite well standard that as competition increases, markups reduces, but as competition increases the market share that a firm gets will depends on the relevance of business-stealing and on its relative efficiency in the market. So that, from our empirical result, business-stealing might hurt more to laggard firms than what the more efficient ones would gain (see Appendix B).

Effect of competition on innovation efficiency. Lets define the innovation expenditure efficiency as the ratio between the probability of success on innovation and the innovation investment. In turn, lets consider that the probability of success on innovation is an increasing function on current innovation expenditure and on managerial quality (or managerial efforts) as defined above.

From our data, we find that as competition raises, firms increase managerial efforts, so that it increases the probability of getting success given a level of innovation expenditure. On the other hand, we also find evidence of a negative causal relationship between competition and innovation investment. Thus, when competition increases it decreases the innovation expenditure, and this reduces the probability of success. By taking into consideration the overall effect of these changes on our measure of efficiency, we are able to claim that if managerial effort decisions respond positive enough to competition, then as competition become more intense, the efficiency of innovation expenditure increases (see Appendix B). Taking these results together, they suggest that increasing competitive pressure reduces the

firm's incentive to invest in cost-reduction innovation, but this competition intensity forces firms to manage this small investment in a more efficient way through a better quality of managerial effort.

6.Concluding Remarks

This paper investigates and quantifies the importance of product competition as a driver of innovation using micro-level data from Uruguayan firms. The estimation of the causal effect of competition on innovation activity dealt with several identification concerns. We find a negative and significant effect of competition on the level of innovation efforts and a positive and significant effect of competition on the efficiency of innovation expenditures. Moreover, these effects are not negligible. An increase in one standard deviation (sd) in competition increases the efficiency in innovation expenditures between 1.0 sd and 2.5 sd depending on the measure of efficiency. This result highlights the important role of antitrust policy as it should safeguard competition. As the markets become a more competitive environment, the innovation expenditure becomes more efficient.

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Appendix A: Tables

Table 1: Descriptive statistics

Variables	Mean	S.D.	Obs.
Competition	0.82	0.09	3,336
Import penetration from China	0.07	0.10	3,336
Innovation outcomes			
Technological innovation	0.38	0.49	3,336
Non-technological innovation	0.20	0.40	3,336
Any innovation	0.43	0.50	3,336
Any innovation: new to the market	0.21	0.41	3,336
Innovation efforts (in %)			
R&D exp. over sales	0.21	1.41	3,335
R&D and capital exp. over sales	1.41	8.52	3,335
Exp. on innovation activities over sales	1.75	8.92	3,335
Efficiency of innovation expenditure on:			
N. of innovators	0.47	1.62	3,309
N. of innovations	0.77	1.85	3,309
N. of *new to the market* innovations	0.23	0.37	3,309
Management practices			
Overall Managerial Practice	−0.06	0.98	2,539
Operations	−0.03	0.98	2,539
Monitoring	−0.06	0.99	2,539
Targets	−0.04	0.99	2,539
Incentives	−0.04	0.97	2,539
Firm's characteristics			
Firm's age	27	21	3,313
N. of employees	90	177	3,336
Holding company dummy	0.15	0.36	3,335

Source: Survey of Innovation Activity Survey 2004–2006, 2007–2009, 2010–2012 and 2013–2015 for innovation variables, management practices and firm's characteristics, Survey of Economic Activity 2003–2012 for competition, and UN Comtrade for import penetration from China.
Note: In the measures of efficiency of the innovation expenditures the denominator is measured in millions of Uruguayan pesos of 2010 (20 Uruguayan pesos is approximately 1 dollar).

Table 2: Evolution of Import Penetration from China

Two-digit ISIC Rev. 3	Year			
	2003	2006	2009	2012
15	0.00	0.00	0.00	0.00
17	0.07	0.25	0.23	0.34
18	0.15	0.36	0.32	0.43
19	0.05	0.16	0.17	0.17
20	0.00	0.01	0.03	0.03
21	0.00	0.01	0.01	0.00
22	0.00	0.00	0.01	0.01
24	0.03	0.05	0.06	0.07
25	0.03	0.06	0.06	0.09
26	0.01	0.05	0.05	0.06
27	0.00	0.02	0.04	0.07
28	0.01	0.04	0.05	0.08
29	0.05	0.11	0.16	0.18
31	0.04	0.07	0.11	0.29
32	0.09	0.19	0.35	0.53
33	0.03	0.09	0.09	0.13
34	0.01	0.02	0.11	0.14
35	0.08	0.22	0.64	0.58
36	0.12	0.32	0.26	0.42
Total	0.04	0.11	0.14	0.19

Source: UN Comtrade for imports from China to Uruguay and exports from Uruguay, and Survey of Economic Activity for domestic production.
Note: Import Penetration from China is the ratio between Chinese imports and apparent consumption (domestic production less exports plus imports) in sector j at year t.

Table 3: First stage estimation: Effect of import penetration from China on competition

Dependent Variable: Competition	OLS (1)	OLS-FE (2)
Import penetration from China	0.208***	0.220***
	(0.064)	(0.063)
Log(Firm's age)	−0.004*	−0.014**
	(0.002)	(0.007)
Log(Firm's age)^2	0.001*	0.002*
	(0.000)	(0.001)
Log(N of employees)	−0.002	0.002
	(0.002)	(0.009)
Log(N of employees)^2	0.000	−0.001
	(0.000)	(0.001)
Holding company dummy	0.002	0.003
	(0.002)	(0.003)
Constant	0.779***	0.791***
	(0.008)	(0.022)
First stage F-statistic	10.567	12.355
R-squared	0.815	0.296
Observations	3,207	2,591

Note: This table presents the first stage estimates for the IV regressions. The dependent variable is competition, the instrument is *Import penetration from China*, and all models include year fixed effects. Column (1) includes industry fixed effects (ISIC Rev 3 at 3 digits), and column (2) includes firm fixed effects. The first stage F-statistic is the cluster-robust F-statistic. Asymptotic standard errors clustered at the industry level are in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 4: Effect of competition on innovation outcomes

	Technological innovation	Non-technological innovation	Any innovation	Any innovation: new to the market
	(1)	(2)	(3)	(4)
Panel A. OLS				
Competition	−0.056	0.063	0.043	−0.030
	(0.118)	(0.137)	(0.142)	(0.136)
Panel B. IV				
Competition	−0.095	0.258	−0.322	0.382
	(0.716)	(0.556)	(0.946)	(0.586)
First stage F-statistic	10.219	10.219	10.219	10.219
Observations	3,234	3,234	3,234	3,234

Note: This table presents the OLS and IV estimates with firm fixed effects for the effect of competition on innovation. Each column estimates the effect of competition on a different innovation outcome. Panel A reports OLS estimates, and Panel B reports IV estimates where competition is instrumented using *Import penetration from China*. All models include industry fixed effects (ISIC Rev 3 at 3 digits), year fixed effects, and the following controls: $Log(age)$, $Log(age)^2$, $Log(employees)$, $Log(employees)^2$ and a holding company dummy. The first stage F-statistic is the cluster-robust F-statistic. Asymptotic standard errors clustered at the industry level are in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 5: Effect of competition on innovation activities

	R&D exp. over sales	R&D and capital exp. over sales	Exp. on innovation activities over sales
	(1)	(2)	(3)
Panel A. OLS			
Competition	0.045	−1.473	−2.509
	(0.319)	(1.462)	(1.519)
Panel B. IV			
Competition	0.187	−13.476**	−12.813**
	(1.196)	(5.615)	(5.639)
First stage F-statistic	10.219	10.219	10.219
Observations	3,233	3,233	3,233

Note: This table presents the OLS and IV estimates with firm fixed effects for the effect of competition on innovation. Each column estimates the effect of competition on a different innovation outcome. Panel A reports OLS estimates, and Panel B reports IV estimates where competition is instrumented using *Import penetration from China.* All models include industry fixed effects (ISIC Rev 3 at 3 digits), year fixed effects, and the following controls: $Log(age)$, $Log(age)^2$, $Log(employees)$, $Log(employees)^2$ and a holding company dummy. The first stage F-statistic is the cluster-robust F-statistic. Asymptotic standard errors clustered at the industry level are in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 6: Effect of competition on innovation efficiency

	Efficiency of innovation expenditure on:		
	N. of innovators	N. of innovations	N. of "new to the market" innovations
	(1)	(2)	(3)
Panel A. OLS			
Competition	2.902**	4.955**	1.360**
	(1.130)	(1.919)	(0.629)
Panel B. IV			
Competition	18.362***	35.033***	11.210**
	(6.150)	(12.208)	(4.438)
First stage F-statistic	10.567	10.567	10.567
Observations	3,207	3,207	3,207

Note: This table presents the OLS and IV estimates with firm fixed effects for the effect of competition on innovation. Each column estimates the effect of competition on a different innovation outcome. Panel A reports OLS estimates, and Panel B reports IV estimates where competition is instrumented using *Import penetration from China*. All models include industry fixed effects (ISIC Rev 3 at 3 digits), year fixed effects, and the following controls: $Log(age)$, $Log(age)^2$, $Log(employees)$, $Log(employees)^2$ and a holding company dummy. The first stage F-statistic is the cluster-robust F-statistic. Asymptotic standard errors clustered at the industry level are in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 7: Effect of competition on management practices

	Overall Managerial Practice z-score	Operations z-score	Monitoring z-score	Targets z-score	Incentives z-score
	(1)	(2)	(3)	(4)	(5)
Competition	0.514**	0.034	−0.033	0.466**	0.880***
	(0.249)	(0.478)	(0.286)	(0.216)	(0.316)
R-squared	0.214	0.078	0.223	0.204	0.075
Observations	2,481	2,481	2,481	2,481	2,481

Note: This table presents OLS estimates for the effect of competition on management practices. Column (1) reports the effect on the general management z-score, column (2) to (5) reports the effect on different management areas. All models include year fixed effects, industry fixed effects and the following controls: $Log(age)$, $Log(age)^2$, $Log(employees)$, $Log(employees)^2$ and a holding company dummy. Asymptotic standard errors clustered at the industry level are in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Appendix B: Theoretical Framework

Our model is close to the unified approach followed by Vives (2008) and Schmutzler (2013), and we introduce uncertainty as Federico et al. (2018) do.

A. Theoretical framework

We consider a set of n firms (indexed by $i = 1, \cdots, n$) that compete in a sequential two-stage game. At the beginning, each firm produces at some baseline of efficiency, i.e. each firm has a constant marginal cost c_i^0, for $i = 1, \cdots, n$. By exerting financial effort z_i, firm i's efficiency level can be improved. More concretely, at time $t = 1$ each firm simultaneously chooses the level of investment in cost-reducing innovation z_i. This financial effort increases the probability σ that that innovation in cost reduction is successful. We assume that probability of get a successful innovation, $\sigma \in [0, 1]$ is a function of financial effort (z_i) and managerial effort (m_i); i.e. $\sigma(z_i, m_i)$. Regarding z_i, that probability is increasing in z_i, $\sigma_{z_i}(z_i, m_i) > 0$, at a decreasing rate $\sigma_{z_i z_i}(z_i, m_i) \leq 0$. Additionally, we assume that probability of get a successful innovation positively depends on firm's managerial effort m_i, i.e. $\sigma_{m_i}(z_i, m_i) > 0$,[19] and $\sigma(z_i, m_i)$ is independent across firms. The cost of z_i, $G(z_i)$, is increasing and convex on z_i ($G'(z_i) > 0$, and $G''(z_i) \geq 0$). Moreover, the cost of m_i, $M(m_i; \phi)$, is also an increasing and convex function on m_i, where $\phi \in \mathcal{R}$ is a parameter that measures the degree of competition. At time $t = 2$, the realization of cost become observable, and if the investment was successful, the marginal cost of firm is $c_i^1 = c(z_i)$ decreasing in z_i ($c'(z_i) < 0$) at a decreasing rate ($c''(z_i) \leq 0$). On the other hand, if the investment was failure $c_i^1 = c_i^0$, so that $c(z_i) < c_i^0$. Let denote by r a particular cost profile from the set S of all possible cost profiles. With n firms, there are 2^n different possible cost profiles, where the i-th entry in r, denoted by r_i, takes value one if i's innovation was successful and zero otherwise. At stage two, by observing its costs and those of its rivals, firms compete in the market by choosing quantities (or prices). Finally profits are realized.

We now characterize the equilibrium in stage two of the model, and then analyze the first-order condition for cost-reduction innovation stage.

Stage two- quantity (price) game. For each firm, and given a realized profile r, the optimization problem at $t = 2$ is

$$max_{h_i}[(p_i - c_i^1)q_i]$$

(where $h_i = q_i$ in case of Cournot competition or $h_i = p_i$ in case Bertrand competition). Let assume that there exists a unique equilibrium $(h_1^*(r, \phi), \cdots, h_n^*(r, \phi))$ yielding a reduced-form profit function

$$\Pi_i(r; \phi), \quad \forall i = 1, \cdots, n$$

---

[19]It is possible to think that c also depends on m_i but, in order to keep things as simple as possible we do not consider this way of analysis.

where $\phi \in \mathcal{R}$ is the degree of competition parameter. Broadly speaking, an increase in the degree or intensity of competition would mean an increase in parameter ϕ, such that that increase would make difficult (if not it renders impossible) to behave as a monopoly, or it would make difficult (if not it renders impossible) to exercise market power. Our empirical exercise uses the Lerner Index as the variable to capture the intensity of competition.[20]

Furthermore, notice that profits at this stage depend on the realized state r. We assume that $\frac{\partial \Pi_i}{\partial c_i} < 0$, $\frac{\partial \Pi_i}{\partial c_j} > 0$, and $\frac{\partial^2 \Pi_i}{\partial c_i^2} \leq 0$.

Stage one- cost-reduction innovation. At this stage, firms simultaneously choose their innovation effort z_i and managerial effort m_i in order to maximize their expected profits under all possible $r \in S$ cost profiles. Let $P[r|z,m]$ denotes the probability of profile r conditional of vector of efforts $[z \quad m]$, and $P[r_{-i}|z_{-i}, m_{-i}, r_i = 1]$ denotes the probability of observing profile r_{-i}, conditional firm i gets the innovation and the vector of effort of other firms is $[z_{-i} \quad m_{-i}]$. Likewise, $P[r_{-i}|z_{-i}, m_{-i}, r_i = 0]$ denotes the probability of observing profile r_{-i} conditional firm i does not get the innovation. Given our independent assumption, $P[r_{-i}|z_{-i}, m_{-i}, r_i = 1] = P[r_{-i}|z_{-i}, m_{-i}, r_i = 0] = P[r_{-i}|z_{-i}, m_{-i}]$.

Notice that firm i gets the innovation with probability $\sigma(z_i, m_i)$, and fails with probability $[1 - \sigma(z_i, m_i)]$. Then, given the independent assumption, we can write the optimization problem at time $t = 1$ as

$$max_{z_i,m_i} \sum_{r_{-i} \in S_{-i}} P[r_{-i}|z_{-i}, m_{-i}] \left[\sigma(z_i, m_i)\Pi(c_i(z_i), r_{-i}; \phi) + (1 - \sigma(z_i, m_i))\Pi(c_i^0, r_{-i}; \phi) \right] - G(z_i) - M(m_i; \phi).$$

In what follows, for simplicity, let us define $\Pi(c_i(z_i), r_{-i}; \phi) \equiv \Pi^{r_i=1}$, and $\Pi(c_i^0, r_{-i}; \phi) \equiv \Pi^{r_i=0}$. Thus, the two FOC of the problem at $t = 1$ are[21]

$$F^1(z_i, z_{-i}, c_i^0, r_{-i}, m_i, \phi) \equiv \frac{\partial \sigma(z_i, m_i)}{\partial z_i} \sum_{r_{-i} \in S_{-i}} P[r_{-i}|z_{-i},, m_{-i}] \left[\Pi^{r_i=1} - \Pi^{r_i=0} \right] +$$
$$+ \sigma(z_i, m_i) \sum_{r_{-i} \in S_{-i}} P[r_{-i}|z_{-i},, m_{-i}] \frac{\partial \Pi(c_i(z_i), r_{-i}; \phi)}{\partial c_i} \frac{\partial c_i}{\partial z_i} - \frac{dG}{dz_i} = 0, \quad (2)$$

---

[20]In the literature, competitive pressure is also parametrized by the number of market participants, the degree of substitutability across goods, the rival's costs, the degree of horizontal differentiation among firms, and so on.

[21]In order to keep things as simple as possible, we prefer to focus our analysis without studying the strategic effect between z_i and z_j. For that, we base on Vives (2008), where he states that "even though R&D investment typically precedes market interaction, this does not mean that it can be used strategically". Moreover, he claims that the evidence on the strategic commitment value of R&D is scant; and in this line Geroski (1991) suggests that strategic effects may be of second-order of importance in innovation incentives.

$$F^2(z_i, z_{-i}, c_i^0, r_{-i}, m_i, \phi) \equiv \frac{\partial \sigma(z_i, m_i)}{\partial m_i} \sum_{r_{-i} \in S_{-i}} P[r_{-i}|z_{-i}, , m_{-i}] \left[\Pi^{r_i=1} - \Pi^{r_i=0}\right] - \frac{dM(m_i; \phi)}{dm_i} = 0,$$

(3)

where equation (2) is the FOC respect to z_i, and equation (3) is the FOC respect to m_i.

Let assume that expected profits are strictly concave on z_i and m_i, and that second-order conditions are satisfied. Moreover, this last assumption ensures the existence of an equilibrium at this stage.

We refer to $F^1(z_i, z_{-i}, c_i^0, r_{-i}, m_i, \phi)$ as the innovation incentives since it measures how profits (in expected terms) change as investment on innovation increases.

From (2), we can identify two reasons why firms have incentive to innovate. First, as a firm increases its innovation expenditure, it increases the probability to have success, and in such a case, it increases profits by $[\Pi^{r_i=1} - \Pi^{r_i=0}]$, i.e., the first term of $F^1(z_i, z_{-i}, c_i^0, r_{-i}, m_i, \phi)$. Second, as innovation expenditure increases, if the firm would get the innovation, the costs will be reduced and, in turn, this will positively impact on profits. This idea is captured by the second term of $F^1(z_i, z_{-i}, c_i^0, r_{-i}, m_i, \phi)$, and it is worth noting that this effect occurs because either the margin $(p(r, \phi) - c_i(z_i))$ increases, and/or because $q(r, \phi)$ increases.

B. The effect of competition on the innovation activities

In what follows we study what determines the impact of the degree of competition (ϕ) on the optimal level of innovation activity carries out by each firm, and on the efficiency of the innovation expenditure. To this end, we concentrate on changes on z_i, m_i, and ϕ.

The total differentiation of $F^i(z_i, z_{-i}, c_i^0, r_{-i}, m_i, \phi)$ for $i = 1, 2$ are given by the following expressions:

$$dF^1(z_i, z_{-i}, c_i^0, r_{-i}, \phi) = \frac{\partial F^1(\cdot)}{\partial z_i} dz_i + \frac{\partial F^1(\cdot)}{\partial m_i} dm_i + \frac{\partial F^1(\cdot)}{\partial \phi} d\phi = 0.$$

(4)

$$dF^2(z_i, z_{-i}, c_i^0, r_{-i}, \phi) = \frac{\partial F^2(\cdot)}{\partial z_i} dz_i + \frac{\partial F^2(\cdot)}{\partial m_i} dm_i + \frac{\partial F^2(\cdot)}{\partial \phi} d\phi = 0.$$

(5)

Effect of competition on innovation expenditure. By solving the system of equations given by (4) and (5), we get the impact of a change in the degree of competition (ϕ) on the optimal level of investment (z_i) as

$$
\frac{dz_i}{d\phi} = \frac{-\overbrace{\frac{\partial F^1(\cdot)}{\partial \phi}}^{(?)}\overbrace{\frac{\partial F^2(\cdot)}{\partial m_i}}^{(-)} + \overbrace{\frac{\partial F^1(\cdot)}{\partial m_i}}^{(+)}\overbrace{\frac{\partial F^2(\cdot)}{\partial \phi}}^{(?)}}{\underbrace{\frac{\partial F^1(\cdot)}{\partial z_i}\frac{\partial F^2(\cdot)}{\partial m_i} - \frac{\partial F^1(\cdot)}{\partial m_i}\frac{\partial F^2(\cdot)}{\partial z_i}}_{(+)}}
\tag{6}
$$

Since we have assumed second order conditions are satisfied for a maximum, then denominator of (6) is positive. Additionally, given our concave assumption, then $\frac{\partial F^2(\cdot)}{\partial m_i} < 0$. On the other hand, since $\sigma(\cdot)$ is an increasing function of its arguments, it is easy to see that $\frac{\partial F^1(\cdot)}{\partial m_i} > 0$ if the impact of a change in m_i in the first term in $F^1(z_i, z_{-i}, c_i^0, r_{-i}, m_i, \phi)$ is of second-order importance. Therefore, the sign of $\frac{dz_i}{d\phi}$ crucially depends on the sign of $\frac{\partial F^1(\cdot)}{\partial \phi}$ and $\frac{\partial F^2(\cdot)}{\partial \phi}$. There is a strand of the theoretical and empirical literature that finds a causal positive relationship between competition and incentives to managerial effort.[22] To some extent, this is in line with what we find from our data, so we state that $\frac{\partial F^2(\cdot)}{\partial \phi} > 0$.

Regarding $\frac{\partial F^1(\cdot)}{\partial \phi}$, this magnitude quantifies the impact of competition on the incentive to innovate, and it is equal to:

$$
\frac{\partial F^1(\cdot)}{\partial \phi} = \underbrace{\frac{d\sigma(\cdot)}{dz_i}}_{+}\underbrace{\sum_{r_{-i} \in S_{-i}} P[r_{-i}|z_{-i}, m_{-i}]\left[\frac{\partial \Pi^{r_i=1}}{\partial \phi} - \frac{\partial \Pi^{r_i=0}}{\partial \phi}\right]}_{A} + \underbrace{\sigma(\cdot)}_{(+)}\underbrace{\sum_{r_{-i} \in S_{-i}} P[r_{-i}|z_{-i}, m_{-i}]\frac{\partial^2 \Pi^{r_i=1}}{\partial c_i \partial \phi}\underbrace{\frac{\partial c_i}{\partial z_i}}_{(-)}}_{B}.
\tag{7}
$$

Accordingly, the sign of $\frac{\partial F^1(\cdot)}{\partial \phi}$ will depend on the sign of A and B in (7), and on their relative magnitudes. Part A captures the effect of competition on the firm's profit *level*. In an industry with symmetric cost across firms, a rise in competitive pressure will reduce each firm's profit level, i.e. $\frac{\partial \Pi}{\partial \phi} < 0$. With asymmetric firms, however, it is possible that a rise in competition raises the profits of the most efficient firm, i.e. $\frac{\partial \Pi}{\partial \phi} > 0$.

On the other hand, part B takes into account the effect of competition on the *slope* of profit function ($\partial \Pi^{r_i=1}/\partial c_i$). Regarding its sign, B can be positive or negative in the case of asymmetric firms. Thus, as the cost decreases, profit level increases but that raise in profits might be smaller when competition is intense. This is might be the case of an inefficient firm to which the positive effect of lower costs on profit is smaller when competition is more intense since it might loss market in favor of more efficient ones. In such that case, the effect of competition for a inefficient firm will be $\frac{\partial^2 \Pi^{r_i=1}}{\partial c_i \partial \phi} > 0$.

Let us observe that if $\frac{\partial^2 \Pi^{r_i=1}}{\partial c_i \partial \phi} > 0$, then $\left[\frac{\partial \Pi^{r_i=1}}{\partial \phi} - \frac{\partial \Pi^{r_i=0}}{\partial \phi}\right] < 0$. Consequently, $\frac{\partial F^1(\cdot)}{\partial \phi} < 0$, i.e. as the competition increases, the incentive to innovate decreases.

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[22]See, among others, Raith (2003), Schmidt (1997), Bloom et al. (2015), Van Reenen (2011), and Cuñat and Guadalupe (2005).

Therefore, by using these results in (6), we are able to claim that we meet the Schumpeterian argument under the following conditions.

Claim 1. *If the expected value of $\frac{\partial^2 \Pi^{r_i=1}}{\partial c_i \partial \phi}$ is sufficiently large and positive, then as the competition increases, a firm decreases its innovation expenditures.*[23]

From Uruguayan firms between 2004–2015, we find that $\frac{dz}{d\phi} < 0$. By taking into account the uncertainty context of innovation investment decision, our empirical result suggests that for Uruguayan firms, the expected positive effect on profits increase due to higher efficiency level is smaller when competition becomes more intense; i.e., $\frac{\partial F(\cdot)}{\partial \phi} < 0$. This is because, when a laggard firm (a relative higher cost firm) gets an innovation, the increase on expected profits from that innovation decreases more with competition than what increase the benefits from innovation that a leader firm (a relative lower cost firm) would get when competition becomes higher.

Effect of competition on innovation efficiency. Now, let us define $\frac{\sigma(z_i, m_i)}{z_i}$ as a measure of the innovation expenditure efficiency.[24]

Before to address the issue about the effect of competition on innovation efficiency, it becomes useful to study the sign of $\frac{\partial m_i}{\partial \phi}$. From (4) and (5), we get that:

$$\frac{dm_i}{d\phi} = -\frac{-\overbrace{\dfrac{\partial F^1(\cdot)}{\partial z_i}}^{(-)} \overbrace{\dfrac{\partial F^2(\cdot)}{\partial \phi}}^{(+)} + \overbrace{\dfrac{\partial F^1(\cdot)}{\partial \phi}}^{(-)} \overbrace{\dfrac{\partial F^2(\cdot)}{\partial z_i}}^{(+)}}{\underbrace{\dfrac{\partial F^1(\cdot)}{\partial z_i} \dfrac{\partial F^2(\cdot)}{\partial m_i} - \dfrac{\partial F^1(\cdot)}{\partial m_i} \dfrac{\partial F^2(\cdot)}{\partial z_i}}_{(+)}} \tag{8}$$

Therefore, $\frac{dm_i}{d\phi}$ will be positive if:

$$\left| \frac{\frac{\partial F^1(\cdot)}{\partial z_i}}{\frac{\partial F^1(\cdot)}{\partial \phi}} \right| > \left| \frac{\frac{\partial F^2(\cdot)}{\partial z_i}}{\frac{\partial F^2(\cdot)}{\partial \phi}} \right| \tag{9}$$

$\frac{dm_i}{d\phi} > 0$ can be interpreted as the argument that firms adapt to increased competitive pressure by raising their productivity (Nickell, 1996).

Now, to study the impact of competition on efficiency, let's take the total differentiation of

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[23]The fact that $\frac{\partial \Pi}{\partial \phi} < 0$, and $\frac{\partial^2 \Pi^{r_i=1}}{\partial c_i \partial \phi} > 0$ both of them characterize what Boone (2000) calls *faint* firms; that is, these firms are far from the efficiency level of their rivals, so that as competition increases faint firms get lower profits and give up on to invest a lot in innovation.

[24]The probability that a cost reduction is successful, $\sigma(z_i, m_i)$, can be computed as $\sigma = \frac{\sum_{i=1}^{n} Innovation(z_i, m_i)}{n}$, where $Innovation(z_i, m_i) \in \{0, 1\}$, and n is the number of firms in the industry.

our measure of efficiency:

$$d\left(\frac{\sigma(z_i(\phi), m_i(\phi))}{z_i(\phi)}\right) = \frac{1}{z_i^2}\left[\left(\frac{\partial\sigma(z_i, m_i)}{\partial z_i}\frac{\partial z_i}{\partial\phi} + \frac{\partial\sigma(z_i, m_i)}{\partial m_i}\frac{\partial m_i}{\partial\phi}\right)z_i - \frac{\partial z_i}{\partial\phi}\sigma(z_i, m_i)\right]d\phi$$

Thus, the impact of a change in the degree of competition (ϕ) on the efficiency of innovation investment ($\frac{\sigma(z_i, m_i)}{z_i}$) is given by the following expression:

$$\frac{d\left(\frac{\sigma(z(\phi), m(\phi))}{z(\phi)}\right)}{d\phi} = \underbrace{\frac{\sigma}{z_i^2}}_{(+)}\left(\underbrace{\frac{\partial\sigma}{\partial z_i}\frac{z_i}{\sigma}}_{(+)} - 1\right)\frac{\partial z_i}{\partial\phi} + \underbrace{\frac{\partial\sigma(z_i, m_i)}{\partial m_i}}_{(+)}\frac{\partial m_i}{\partial\phi}\underbrace{\frac{1}{z_i}}_{(+)}$$

or equivalently,

$$\frac{d\left(\frac{\sigma(z(\phi))}{z(\phi)}\right)}{d\phi} = \frac{\sigma}{z_i^2}(\varepsilon_z - 1)\frac{\partial z_i}{\partial\phi} + \frac{\partial\sigma(z_i, m_i)}{\partial m_i}\frac{\partial m_i}{\partial\phi}\frac{1}{z_i}, \tag{10}$$

where $\varepsilon_z > 0$ is the elasticity of σ to z_i.

From our data, we find that $\frac{d\left(\frac{\sigma(z)}{z}\right)}{d\phi} > 0$. Since we also find that $\frac{\partial z_i}{\partial\phi} < 0$, then by using (10), we are able to claim the following.

Claim 2. *In the context of asymmetric firms, as competition becomes more intense, the efficiency of innovation expenditure increases when managerial efforts respond positive enough to competition.*

Therefore, taking our two empirical results together, they suggest that increasing competitive pressure reduces the firm's incentive to invest in cost-reduction innovation, but this competition intensity forces firms to manage this small investment in a more efficient way through a better quality of managerial effort.