Measuring Innovation in Agricultural Firms: A Methodological Approach

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Abstract: Measuring innovation is a notoriously difficult task. Agricultural firms present additional complications due to the complexities and uncertainties linked to the sector. Among the increasing literature available on innovation, there is plenty of information about innovation measurement in manufacturing industries, but scarce contributions for the case of agricultural firms. Currently there is no concerted and/or published methodology for innovations measurement for such firms. This research proposes a methodology for measuring innovation and its key determinants in agricultural firms, based on three main tools. The first one is the Innovation Matrix (IM), an approach to a structured catalogue of the technology in the agricultural subsector under study. IM includes information about innovation technological level, in terms of its place on the technological spectrum of the subsector. IM also includes information about the frequency of innovation, which refers to the degree of adoption of a particular innovation among the farmers. The second tool is the Innovation Index (II), a single number that combines information about the technological level and frequency of the observed innovations. The basic idea of II is to assign higher values to firms that implement either less frequent or comparatively advanced innovations, relative to the ones implemented by its competitors. Since II is always a real non-negative number, it is possible to use OLS estimation procedures (third tool) to enquire about the factors driving innovation processes in agricultural firms. We have applied this methodology to four agricultural subsectors in Colombia. The II results reveal relatively small values for most of the surveyed producers. At the same time, they provide evidence to support the claim that there are just a few innovative leaders in every chain. In general, the factors determining innovation are subsector-specific, but there are still some general stylized facts for the whole agricultural sector. The main consequence of this finding is that innovation policy design for the agricultural sector must take into account the existence of both sectorial (common) and subsector (specific) factors.

Keywords: innovation matrix, innovation index, measure of innovation, agricultural firms, innovation drivers, transactional model

1. Introduction

Agriculture in Colombia, as in the rest of the world, is a strategic sector. It has different roles and opportunities for essential development of the nation, mainly in food safety and food quality, interdependence with other sectors of economy, control of inflation, bioenergy production, institutional stability, and custody of natural resources (Banco Mundial, 2008a: 125; Banco Mundial, 2008b: 15; CAF, 2006: 3-4; Londoño, 1985: 5; Rugeles, 1986: 96-147; among others).

Colombian agriculture has good perspectives facing these challenges. We need to be aware, in any case, about the necessity of overcoming major constraints in order to consolidate modern agricultural production capable of competing in a global market, producing quality food both for the internal market and for exports, and one that produces positive effects in the territories where it operates. Our agriculture, with some exceptions, is mainly composed of small productive units, dispersed throughout the territory, informal economies and low levels of technology.

Agriculture is the fourth most important economic activity within the structure of Colombian GDP and represents 8% of the total (DANE, 2007). If agriculture and agroindustry (4.5%) are combined, the share reaches 12.5% and occupies the first place. However, the annual growth of the agricultural sector in the long run has lagged behind the overall growth of the economy (DANE, 2012), particularly in the critical years 2009 and 2010 in which agriculture shrunk by -0.7% and grew by 1.0% respectively.

Innovation is a key factor for economic growth, development and the welfare of nations. Measuring innovation is useful because it may provide orientation for the nature and degree of development of society

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towards a better future. In the agricultural sector, innovation measurement is a recent task, which has just begun with the design and implementation of surveys and some theoretical reflections about it. This state of things differs from the advances attained in the industrial sector (Lugones, 2003: 2; Anlló, Lugones and Suárez, 2009: 100; Malaver and Vargas, 2007: 2-3; Olaya and Peirano, 2007: 170). The lag observed in innovation measurement for agricultural firms is a common issue all over the world, even in developed countries, and is not an exclusive feature of Colombia.

Our research group belongs to a network of universities that studies different aspects of agribusiness firms and their relationship with territorial features in several Colombian regions. The last three years (2009-2012) our group has studied agricultural firms in six subsectors and five territories in Colombia. In this article, results and analysis are focused on four subsectors and four territories. These sectors are potato, cut flowers and pork meat in Cundinamarca and Antioquia and palm oil in Meta and Magdalena. The main objective of mentioned research has been examining the structure and nature of transactional models of agribusiness in order to understand whether these models influence the innovation process. Our fundamental assumption is that low capacity to generate innovation in Colombian agricultural sector, is not so much related to lack of technology but lack of adequate transactional models. The research also attempts to find out if regional innovation networks and inter-firm innovations influence the innovation process.

This paper wants to summarize the methodological tools that we have developed to achieve these goals. The main finding of the research is a new methodology for measuring innovation in agribusiness firms. The key pieces of this methodology are the innovation matrix, the innovation index and the econometric model that accompanies it for analysis. The first one is an ordered inventory that summarizes the nature and features of observed innovations in a particular subsector. The second one summarizes both the qualitative and quantitative aspects of the innovations implemented by a firm in a given subsector. Finally, using an econometric model it is possible to identify the key factors that drive innovation in the chosen subsectors.

Besides this introduction, the paper has six additional sections. The second one describes the current methodological approaches to study innovation processes in agribusiness firms. In the third section the innovation matrix is introduced and explained. Section four presents the innovation index as a new way of measuring innovation in the agribusiness sector. In section five we explain briefly a direct application of our proposed methodology, using an econometric model to identify the key variables that influence innovation in four agricultural subsectors. Section six explains the main results. Section seven presents the conclusions.

2. Methodological approaches

There are two main types of econometric models in the literature concerning studies of innovation in agribusiness firms. The first one uses Probit (or Logit) models (Avermaete et al, 2003a: 12).The second one uses Ordered Logit models (Nossal and Lim, 2011: 18). Both families share a common strategy that we can divide in four stages:

1. For a given economic subsector, the researcher compiles an inventory of innovations in the firms that belong to it.

2. The researcher defines a classification system for these innovations. The main focus of the classification varies greatly. One possibility is to focus on the rupture level of the innovations (radical and non-radical innovations respectively). Usually such classification is based on Oslo Manual (OECD and Eurostat, 2005: 58-63) and Bogotá Manual (Jaramillo, Lugones and Salazar, 2001: 33). This classification focuses on the type of innovation, that is, product, process, organizational or market innovation. According to Avermaete et al (2003b: 8) is also possible to subdivide those initial groups. For example, within the group of product innovations some subgroups can be defined, such as the change in visual appearance, new package materials, etc.

3. The observed innovations in the sample are classified using the full inventory of innovations and the classification system as described in the first two stages.

4. Finally, the observed innovations are used to compute the degree of innovation of every firm. The exact mechanics of measuring innovation depends on the final econometric model to be applied. One alternative is

to construct an average innovation, allocating different weights to every innovation. Another possibility is to count the innovations and assign an innovation measure following pre-established rules. For example, the rule dictates that the firm is a high innovator if a minimum of three “great extent” innovations is observed (Nossal and Lim, 2011: 13).

The two main types of econometric models already mentioned differ mainly in the fourth stage. Probit and Logit models use a discrete measure using 1 and 0 values, depending on whether or not the firm presents innovations and meets other criteria, like investment in R&D or registered patents. Ordered Logit models use a variable with discrete and ranked ordinal values (assigning higher values to firms with better innovation performance).

Some studies propose measuring the innovation from proxy variables, such as total R&D investment, the proportion of engineers and scientists participating in R&D activities of the number of patents the firm holds. Those studies have been questioned, mainly because their limited validity, in other words, because these activities do not always lead to innovations. On the other hand, some point out that these studies imply a limited understanding of innovation, which is often assumed as a linear process (Knickel, Tisenkopfs and Peter, 2009: 7). Some of the alleged limitations of these studies of innovation measurement are:

- They show a lack of consistency between the definition of innovation and its measurement (Johannessen, Olsen and Lumpkin, 2001: 22). One thing is that entrepreneurs have features associated with innovation capacity, and another entirely different aspect is that they incorporate innovations effectively.
- They have a strong focus on R&D that suggests innovation is a linear process. However, recent studies show that innovation may be a systemic process (Hall, Mytelka and Oyeyinka, 2006: 7; Nelson and Winter, 1982; Edquist, 1997 in Johannessen, Olsen and Lumpkin, 2001: 22-23). On the other hand, since a great proportion of agricultural innovations originates in R&D activities outside the agribusiness firm (Nossal and Lim, 2011: 9), it is not always the case that R&D within the firm is a proper index to measure innovation.
- By focusing on the proportion of engineers and scientists involved in R&D activities, this approach does not take into account other members of the organization that can be equally important for innovation activities within the firm (Johannessen and Hauan, 1994 in Johannessen, Olsen and Lumpkin, 2001: 23).
- The use of patents and copyrights as indicators of innovation for agribusiness firms has limited applicability. Diederen et al (2003: 46-47) found that obtaining patents is not a main concern among Dutch farmers, since such protection is not very useful if the diffusion of innovation has little effect on the final production costs for the farmer. Nossal and Lim (2011: 9) sustain that ‘many agricultural innovations are not patentable; for example, new production practices (such as changing rotations or tillage techniques) have large productivity benefits, but cannot be patented by the farm manager’. In this sense innovations ‘may take other forms than only those that it is possible to patent’ (Johannessen, Olsen and Lumpkin, 2001: 23).

For all these reasons, it is not particularly effective to use these indicators for innovation measurement in agricultural firms.

The exogenous variables used in the aforementioned econometric models depend on the goals of the researcher. In general these variables focus on the features of the firms (e.g. their size or antiquity), their leaders (age, experience, education, etc.), their integration to innovation or entrepreneurial networks, relevant aspects of their economic sector (its size, the nature of their clients) and regional and sectorial features.

It can be argued that this basic methodology is, at to some point, arbitrary. In the Logit/Probit models the same firm can be innovative or non-innovative depending on the threshold used. On the other hand, in the ordered Logit models the degree of innovation of a firm can increase or decrease depending on the rules to assign the innovation rank of a firm.

However, the main shortcoming of these strategies is that they do not take into account two fundamental properties of the innovation itself. The first one is that every innovation is different, in the sense that each innovation belongs to a different part of the technological spectrum of the economic subsector being analyzed. Secondly, every innovation has a different frequency within the economic subsector. Some innovations can be very common whereas others will be extremely rare. In order to exploit these features we first need an additional tool, the innovation matrix.

3. Innovation matrix (IM)

The Innovation Matrix (IM) is a structured instrument developed for a spread sheet application (in our case Microsoft Office Excel ®). The purpose of this instrument is to organize in a systemic and synthetic way information gathered about innovation through the implementation of an innovation survey. This survey was applied to a sample of farmers belonging to the chosen sub-sectors studied in this paper, in a reference period of five years (2006-2010). The IM allows a deeper understanding of the nature and characteristics of the innovations made by the surveyed producers. The IM is particular to each subsector; the defining elements of the technology spectrum in the flowers subsector flowers are completely different to those observed in the potato subsector.

The rows in the IM contain details of each innovation according to different analytical interests. The columns represent, on one hand, these lines of analysis, and on another, the list of innovations present in a particular surveyed producer (Figure 1). The analytical axes are: 1) types of innovation as defined by the Oslo Manual (process, product, and market organization), 2) innovation paradigms, 3) fields of innovation and 4) innovation types according to their degree of technological innovation. Reading information horizontally in the IM provides knowledge on the characteristics of a given innovation and its frequency within the sample of surveyed farmers. Meanwhile, reading information vertically in the IM reveals the number of innovations for a given farmer, which together with their technological level and frequency will determine the value of the innovation index for each entrepreneur (see Section 4).

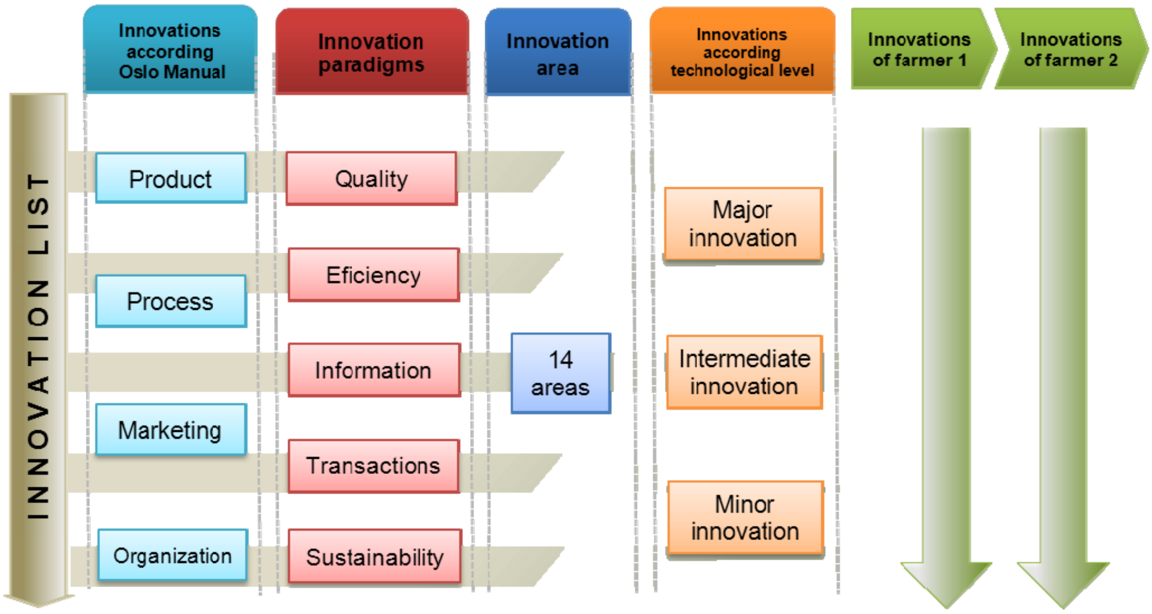

Figure 1: Innovation matrix structure

The technological degree of an innovation refers to those technological features implemented by the firm, in terms of their distance with respect to the knowledge frontier in a given thematic area. With this perspective and based on the judgment by experts, innovations were classified in three main groups: major, minor and intermediate.

First, there are innovations that are the closest to the technological frontier. Such innovations are usually used by a small amount of the firms in the subsector and they have advanced technological level in a certain aspect. They are called *major innovations*.

On the other hand, we find innovations that are mainly implemented (but not exclusively) by technologically "laggards" firms (see Diederen et al, 2003: 31). These innovations have basic technological level in a certain aspect. They represent minimal changes, those that firms must perform to stay in business. They are called *minor innovations*.

Finally, there are innovations that cannot be easily categorized in any of the previous extremes. These innovations have average technological level in a certain aspect. They do not create a sudden change in the technological trend of the subsector and express themselves as incremental positive changes for the firm. They are called *intermediate innovations*.

The incorporation of different types of innovation depends on the firm's capability. This capability is expressed by certain characteristics inherent to the farmer, to the production unit or company and its relationship with the operating environment, to the extent that these features support innovation (Nossal and Lim, 2011: 4-5). Likewise, it should be recognized that the effect or impact of each innovation on the firm's performance is different. The most important and complex issue is that an agribusiness company can incorporate simultaneously the three types of innovation to solve a problem. This can be seen as a consequence of the fact that the process of natural innovation in agribusiness firms tends to be sequential (Nossal and Lim, 2011: 9), often derived from structured and unstructured experimentation and includes major (radicals) and small improvements (Hall, Mytelka and Oyeyinka, 2006: 11; Leitbeg et al, 2008: 4). Considering the previous arguments, typifying innovation in terms of technology degree assumes that innovations are not equal from the point of view of the features of incorporated technologies, the technology impact and the required entrepreneurial skills. Taking this fact into account will allow an assessment of the innovation process of farmers more consistent with the reality of agribusiness firms.

Once the surveys were processed, it was clear that innovations carry more information than their technological level. The frequency of an innovation within the subsector allows a completely different analysis. Some are extremely rare, implemented by a handful of firms. On the other hand, other innovations are very popular, with a huge diffusion within the subsector. It is important to point out that the frequency of innovation refers to the degree of adoption of an innovation among farmers.

However, there is no correlation between these two types of attributes, technological level (qualitative) and frequency (quantitative). Both major and minor innovations can be either rare or extremely common within a subsector. This lack of correlation was the inspiration for a way of summarizing in a single numerical index both features. This is the innovation index, to be explained in the following section.

4. Innovation index (II)

The basic idea of the Innovation Index (*II)* is to assign a single numerical value to the set of innovations of every firm. Such numerical valuation must assign higher numbers to innovations that push the technological frontier or to innovations that are relatively rare within the subsector. The same approach must be used for intermediate innovations. In this case a higher valuation must be given to those with a lower frequency.

The qualitative and quantitative ways of classifying the innovations present in each firm can be drawn in a plane. The horizontal axis will represent a measure of the relative frequency of the innovation, how the firm behaves with respect to its competitors. The vertical axis will represent a measure of the innovation type, that is, if the firm implements a major, intermediate o minor innovation (according to the IM).

We propose a *II* that uses information of the two axes and summarize it in a single number. The *II* of an agribusiness firm in a given sector is defined by:

$$II = \sum_{j=1}^{n} \mathbf{1}_j f_j^{k_j}$$

where sub-index *j* refers to the *j*-th innovation in the IM, *n* is the total number of innovations in the analyzed subsector, $\mathbf{1}_j$ is an indicator function that tells us whether or not innovation j-th is implemented by the firm and f_j is the relative frequency of *j*-th innovation in the sample (in relation to the competitors of the firm within the subsector). Finally, power k_j is equal to -1, -1/2 and 0 for major, intermediate and minor innovations respectively. Indicator function $\mathbf{1}_j$ plays a key role, since a particular innovation adds value to *II* only when is implemented by the firm. This means that there is a third feature incorporated to the *II* (besides the technological level and frequency of the innovations), the number of innovations implemented by the firm.

Frequencies are measured in the interval $(0,1]$. Since this frequency is raised to a particular power (depending on the technological level of the innovation), rare and major innovations are rewarded with the highest contributions to *II* (contributions higher than 1). Minor innovations add 1 to *II*, whether they are common or rare. Every innovation implemented by the firm increments the value of *II*, there are not negative innovations.

The following are some of the properties of the *II* from a mathematical point of view.

First, the minimum value of *II* is 0, for a firm with no innovations. The maximum value of *II* is given by the extreme case when a single firm implements all possible innovations in the subsector and the remaining firms do not implement any one. Let us call the number of minor, intermediate and major innovations as $n_1, n_2 y n_3$ respectively. Then:

$$n_1 + n_2 + n_3 = n$$

The number of firms in the sample is p . Since only one firm implements all possible innovations and the remaining firms do not implement a single one, the frequency of every innovation will be $\frac{1}{p}$. In this case, *II* will be:

$$II = \sum_{j=1}^{n_1} p^0 + \sum_{j=n_1+1}^{n_1+n_2} p^{\frac{1}{2}} + \sum_{j=n_1+n_2+1}^{n} p$$

$$= n_1 + n_2 p^{\frac{1}{2}} + n_3 p$$

This value is the maximum in the general case. If all innovations are major, the maximum value of *II* is

$$II_{max} = np$$

Hence, *II* belongs to the interval $[0, np]$ for every firm in the sample.

It is quite important to point out the dynamic nature of *II*. Our survey asks the firms about innovation activities during the last five years. Therefore, *II* only captures the innovation activities of the firm in this time frame. A highly innovative firm can have a low *II* if most of its innovations (or at least its major and rare ones) were implemented outside the observation period, or if a high number of innovations are minor or have relatively high frequency.

It is also important to clarify that *II* is a random variable, since its final value depends on the observed sample. It is not strange for an index to be a random variable. For example, a Consumer Price Index (CPI) is a random variable, since every element of its computation is random: the products chosen, the observed prices, the selected cities and sellers, etc.

5. A linear regression model

The firms to be interviewed were chosen using a random stratified sampling. The key stratifying variable was the transactional models of agribusiness used by the firm. The different types of transactional models used in a particular subsector were determined in the initial research. Since every firm in the survey has a main transactional model, this feature is a proper stratifying variable.

The dependent variable (the *II* or some function of it) is continuous; hence the usual econometric models used to study innovation (Logit/Probit or Ordered Logit models) are no longer applicable. A linear regression model is proposed where the main endogenous variable is *II* or a functional form of it.

The key exogenous variable in our proposed econometric framework is the transactional model used by the firm, since the goal is to determine the effect of such transactional models on the innovation of the firm. More exogenous variables are used as controls. All of them are used regularly in the literature on innovation. Such variables include those that describe the nature of the firm, its leader and those that capture their relation to the innovation system.

As in every linear regression model it is important to verify a number of assumptions that guarantee the quality of the numerical estimates of its parameters and the inferential processes applied to them. For purposes of our research, the following are the main assumptions to be used (we include for completeness the statistical tools to verify them):

- The linear regression model has the proper functional form. The Box-Cox test was used to determine the particular functional form, among linear, logarithmic or semi-logarithmic options.
- The disturbances of the linear regression are homoscedastic. We have used White and Breusch-Pagan tests depending on the features of the linear regression under study.
- The disturbances are normal (gaussian). We have used Jarque-Bera test to check this assumption.

Using the Box-Cox test we have concluded that the proper functional form is a semi-logarithmic one. Therefore, our econometric model will be:

$$\log(II) = X\beta + u$$

where $\log(II)$ is the natural logarithm of the *II*, u is the disturbance, X is a matrix that summarizes all exogenous (explanatory) variables, and β is a vector with the parameters of the model. The estimates of β represent semi-elasticities of the innovation with respect to the exogenous variables.

The exogenous variables to be included in X depend on the subsector to be analyzed. However, it is worth mentioning briefly all the possible variables to be included in the final econometric model. These variables, their concepts and descriptions are explained in Table 1.

Table 1: Exogenous variables for the linear regression model

Variable	Type	Concept	Construction
Region	Dummy, with values 0 and 1.	There are two regions in every subsector. The region with lower average *II* was used as reference.	Taken directly from the survey.
Transactional Model	Dummy, with values 0 and 1 for every type of model.	It distinguishes the transactional model used for the firms in the subsector. In all sectors model 1 (M1) is used as reference. The exact definition of every model depends on the sector to be analyzed.	We assign a transactional model to every surveyed firm, according to the interpretation of the survey's answers.
Scale of Production	Real variable, measured in millions of Colombian pesos.	The amount of annual sales of the firm.	Information taken directly from the survey.
PARTI	Integer values in the interval 0-6.	Acronym that stands for "Participación en Redes Territoriales de Innovación". This variable summarized the number of actors the firm is involved with in Regional Innovation Networks.	The value of this variable is the sum of six dummy variables, one for each actor in Regional Innovation Networks: government, universities, research centers, guilds, NGO and research networks.
VIF	Integer values in the interval 0-4.	Acronym that stands for "Vínculos Inter Firma". This variable summarizes the number of actors the firm is involved with in innovation activities.	The value of this variable is the sum of four dummy variables, one for each actor in innovation activities: suppliers, clients, other firms and consultants.
R&D	Dummy, with values 0 and 1.	It evaluates whether or not the firm performs Research & Development activities.	Information taken from the survey.

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Variable	Type	Concept	Construction
Education Level of the Leader.	Dummy variables, with values 0 and 1.	This set of dummy variables measure the highest educational level of the leader of the firm. Those levels are: none, primary, high school, technical degree, technological degree, university degree and postgraduate degree. The base level is different in every subsector.	Variables built from the information in the survey.
Age of Leader	Integer variable	It measures the age (years) of the leader of the firm.	Information taken from the survey.
Experience of Leader	Integer variable	It measures the experience (years in the sector) of the leader of the firm.	Information taken from the survey.

6. Results

6.1 What type of innovations the surveyed farmers incorporate?

Intermediate innovations are the most popular among the surveyed farmers of all subsectors studied (Table 2). This result may indicate that farmers are moving towards the technological frontier of their respective subsector and not just concentrating on incorporating minor innovations that would probably push them out of business. Minor and major innovations are relatively rare in number, but their adoption rate is comparatively high in most of the subsectors, particularly in cut flowers and pork. These results agree with previous studies on the nature of the innovation process, characterized by its sequential and incremental nature, introducing both radical and minor improvements into the production system.

Table 2: Number and frequency of innovations according to technological level

	Potato		Cut Flowers		Pork Meat		Palm Oil	
	Number	Frequency	Number	Frequency	Number	Frequency	Number	Frequency
Minor innovations	14	76%	12	85%	10	87%	24	90%
Intermediate innovations	60	94%	61	97%	51	99%	42	99%
Major innovations	8	27%	17	83%	18	91%	15	62%
Number of Innovations per Subsector	82		90		79		81	
Number of Surveyed Farmers per Subsector	79		71		78		79	

Note: Frequency is the percentage of total farmers in the survey who have incorporated at least one such innovation.

Figure 2 shows the distribution of innovations by type of innovation as defined by the Oslo Manual. First, the similar distribution must be pointed out regarding the number of innovations, classified by their types, in the four subsectors. The largest proportion of innovations incorporated by the surveyed firms belongs to the process innovations type. This coincides with previous studies of innovation made in agribusiness firms in The Netherlands (Diederen et al, 2003: 34) and Australia (Liao and Martin, 2009: 4-10; Nossal and Lim, 2011: 12). In that sense, it is observed that most of the innovations identified through the survey are aimed at improving the process of production or distribution of goods, either in terms of cost reduction or efficiency.

Organizational innovations have the second major proportion, with a significant number of innovations for the pork (32%), cut flowers (29%), palm (20%) and potato (18%) subsectors. This result is particularly important as innovations in organization were recognized as such by the Oslo Manual only until its third edition (2005). More precisely, the Oslo Manual recognizes that organizational innovations are not only a supporting factor for product and process innovations, but by their own right can significantly influence the performance of firms, allowing quality improvement and work efficiency, promoting information exchange, providing companies with greater learning capability and encouraging better use of new knowledge and technologies (OECD and Eurostat, 2005: 62-63).

Innovations in marketing and product are low in the analyzed subsectors (Figure 2). These results reflect somewhat limited differentiation, quality and service demands, but also the low rate of incorporation of these types of innovation and lack of motivation to catching up among the surveyed farmers. It is likely that innovations in organization and marketing can promote the development of process and product innovations, given the high interdependence between these types of innovation (OECD and Eurostat, 2005: 18). Analytical and conceptual approaches to the product and marketing innovation processes in agribusiness firms must be the subject of future research, considering the influence of these developments on the competitiveness of the country's agricultural subsectors.

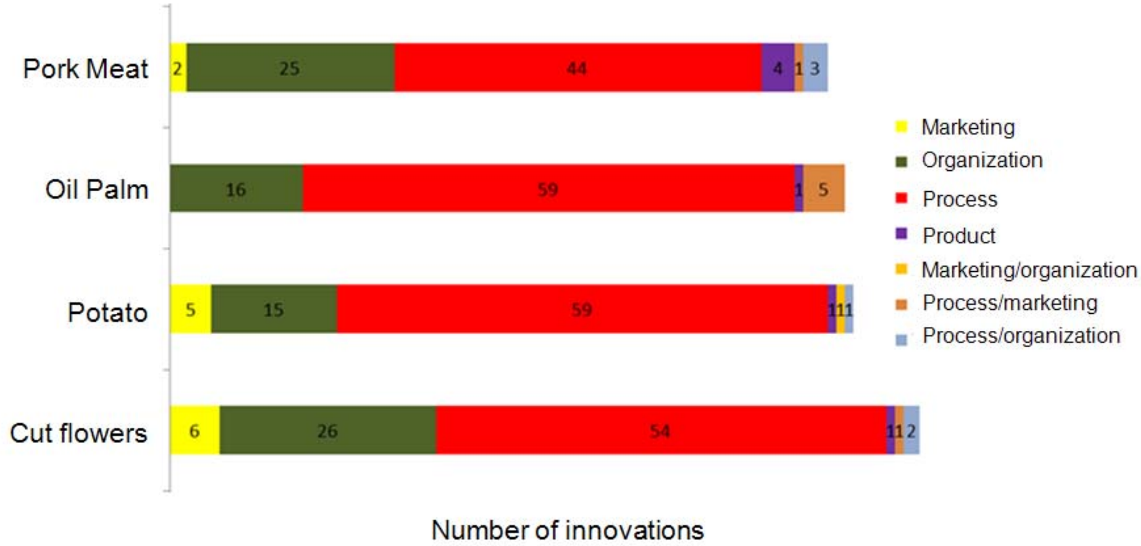

Figure 2: Innovations according to the Oslo manual in the analyzed subsectors

It is interesting to highlight the strong bias towards innovations characterized by an intermediate technological level, process-centric and focused on improving the efficiency of production systems in all subsectors. In this perspective, the bulk of innovations found in the surveyed firms are responding to traditional agricultural problems with conventional technologies, far from the knowledge frontier, without significant efforts in new areas of innovation that take into account market signals. These limited efforts explain the problems of competitiveness of the country's agriculture. Although the determinants of this scenario are multiple, we propose future research on two determinants. The first one relates to the reluctant attitude of the entrepreneur towards market tensions as engines of change. Some producers are closer to markets and have a higher degree of compliance with quality and sustainability requirements. These producers show greater inclination towards innovation.

The second one is about the R & D field in the country. As a source of knowledge and technology creation, the agricultural sector is still highly dependent on public funding. The medium-term events in the System of Agricultural Science and Technology have affected their ability of catching up and incorporating technological and non-technological offerings that effectively boost the innovation process in firms.

6.2 Innovation Index in Agribusiness firms

Making comparisons in terms of the Innovation Index (*II*) is not recommended because the number, nature, degree and frequency of technological innovations are particular to each subsector. However, this type of analysis provides useful guidelines for sectorial analysis and particularly for innovation policy.

Table 3 presents the average values of the Innovation Index ($(\overline{II})$) for the subsectors and regions analyzed. Interestingly, the pork sector reports the highest $\overline{II}$, while the potato sector has the lowest. These results agree with the proportion of minor and major innovations for these subsectors. The pork subsector reported a low number of minor innovations and a high number of major innovations, whereas the potato subsector has the lowest number of major innovations (Table 1). It is evident that there is a strong positive relation between the *II* and the number of major innovations. The effect of frequency is lower, possibly due to different types of innovation incorporated at the same rate by farmers.

Table 3 also shows regional differences in the innovation of firms in the same subsector, particularly in the potato subsector. Palm and pork firms have similar mean values for *II* in both regions. This means that for some subsectors innovation processes are more homogeneous. The reason of this phenomenon is that producers tend to incorporate almost the same proportion of innovations with different degrees of technological innovations and also with a similar frequency. Necessary actions should be aimed at closing regional gaps, and looking for a higher and more homogeneous *II* for most of the farmers.

Table 3: Results of innovation index for the subsectors and regions analyzed

	Potato		Cut Flowers		Pork Meat		Palm Oil	
	Antioquia Region	Cundinamarca Region	Antioquia Region	Cundinamarca Region	Antioquia Region	Cundinamarca Region	Magdalena Region	Meta Region
$\overline{II}$ *per region*	11	38	30	46	49	42	32	26
$\overline{II}$ *per subsector*	24		37		45		29	
Maximum II per subsector	312		129		118		400	
Minimum II per subsector	0		1		1		2	

6.3 Determinants of Innovation

Table 4 summarizes results of the econometric model applied to cut flowers, palm oil, potato and pork meat subsectors. Variables PARTI and VIF are computed as the sum of the dummy variables that compose them, and we call this the aggregated case; we also computed them in disaggregated way, but the results are not reported in this paper. We have included only those variables that are significant by at least 10% and the p-values are reported in square parentheses. We also report R^2 and whether or not White robust variance estimation procedure was used (if heteroscedasticity was detected). It is important to recall that if a firm does not present any innovations within the five years window, *II* is equal to zero and that firm is excluded from the sample used for the estimated model (the logarithm of *II* is not defined in that case). That is the case only for the potato subsector.

Table 4: Econometric model results for four different agricultural subsectors, aggregated case

	Subsector			
Variable	Cut Flowers	Palm Oil	Potato	Pork Meat
Constant	1.879961	2.476425	2.160563	3.478122
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Region	0.563451	—	0.54239	—
	[0.0037]		[0.0049]	
Business Model 2	—	0.782182	0.474906	—
		[0.0002]	[0.0161]	
Business Model 3	0.401043	0.709593	—	0.798013
	[0.0409]	[0.0003]		[0.0008]
Business Model 4	0.780057	—	—	0.544716
	[0.0015]			[0.0014]
Scale of production	—	0.000027	0.000121	—
		[0.0476]	[0.0000]	
PARTI	0.228626	0.148039	0.25903	0.174707
	[0.0007]	[0.0119]	[0.0038]	[0.0168]
R&D	0.337052	0.356451	—	—

	Subsector			
Variable	Cut Flowers	Palm Oil	Potato	Pork Meat
	[0.0434]	[0.0523]		
Basic Education	-2.036604	—	—	—
	[0.0000]			
Technological Oriented Education	0.801274	—	—	—
	[0.002]			
High School Education	—	—	—	-0.908015
				[0.0031]
Postgraduate Education	—	—	1.096886	—
			[0.0312]	
No Education	—	—	—	-3.339088
				[0.0000]
Age of leader	—	-0.01337	—	—
		[0.0463]		
Experience of leader	0.016322	—	-0.017204	-0.020061
	[0.0557]		[0.0207]	[0.0421]
Number of employees	—	0.001818	—	—
		[0.0006]		
Observations	71	79	75	78
R^2	0.726238	0.561467	0.529611	0.487436
White Robust Variance Computation	No	No	Yes	Yes

Even more interesting than the estimated coefficients is their interpretation. Since the model is semi-logarithmic, every coefficient (say *b*) can be interpreted as a semi-elasticity: other things being equal, an extra unit in the respective independent variable will cause an increment/decrement (depending on the sign) of $100*(\exp(b)-1)\%$ in the *II* (with special care in the interpretation of the dummy variables, which refer always to the base category). Table 5 summarizes the semi-elasticities for the analyzed subsectors.

Table 5: Semi-elasticities for four different agricultural subsectors, aggregated case

	Subsector			
Variable	Cut Flowers	Palm Oil	Potato	Pork Meat
Constant	555.324928	1089.86506	767.602088	3139.88199
Region	75.6724508	—	72.0113023	—
Business Model 2	—	118.623743	60.7863051	—
Business Model 3	49.3381483	103.316359	—	122.112317
Business Model 4	118.159661	—	—	72.4118663
Scale of production	—	0.00270004	0.01210073	—
PARTI	25.6871881	15.9558118	29.5672674	19.0897233
R&D	40.0811904	42.8251544	—	—
Basic Education	-86.9528961	—	—	—
Technological Oriented Education	122.837807	—	—	—
High School Education	—	—	—	-59.6675972
Postgraduate Education	—	—	199.48256	—
No Education	—	—	—	-96.4530709
Age of leader	—	-1.32810186	—	—
Experience of leader	1.64559315	—	-1.70568562	-1.9861117
Number of employees	—	0.18196536	—	—

Regional factors have an impact on the *II* for the cut flowers and potato subsectors. The transactional model used by the firm has an incremental effect on the innovation in all subsectors, taking as the base group the classical market model. It is important to point out that for all practical purposes this model is defined as the case when the farmer does not know in advance who will buy the goods. When the transactional model is prone to avoid uncertainty (models 2 and superior have features such as existence of contracts, vertical integration, etc.) the *II* increases. This finding suggests that a policy designed to increase the formalization of economic transactions in the agricultural sector will have positive effects on the innovation performance. Of course, there must be further research in this particular subject, since there is a lack of results in this matter.

Education of the leader of the firm tends to have a positive effect on the *II*, with the exception of the pork meat subsector (in particular, high school education has a negative effect) and the cut flowers subsector (basic education has a negative effect on the *II*, but in this case the base education is high school or higher education).

Participation in research networks (PARTI) has a positive effect in all subsectors. R&D show a positive effect only in the cut flowers and palm oil subsectors, which are the most "industrialized" of the subsectors analyzed, having established research centers and being export-oriented. Pork meat and potato subsectors do not show a relevance of R&D for innovation, but this may be a product of weak R&D practices. This result does not cast doubt on the positive impact that this practice may have on the subsectors. What the results do suggest is the need to inquire about the role of the farmer's own R & D and other factors that come into play in the adoption process of innovations. Again, further research on this particular point is necessary. In any case, policies to stimulate innovation via R&D must take into account specific features of each subsector.

Finally, in all subsectors the age of the leaders or their experience have negative effects on the *II*, with the exception of the cut flowers subsector. This may suggest that an experienced leader is more conservative and he is averse to implement innovations.

7. Conclusions

This study has proposed a new methodological approach to measure innovation in agribusiness firms. This approach is based on three tools: the Innovation Matrix (IM), the Innovation Index (*II*) and the econometric model (OLS estimation procedures).IM provides a landscape of the current state of technology in a given agricultural subsector. It catalogues and categorizes (in multiple ways) any possible innovation implemented by a firm of the subsector. The main objective of this categorization was to determine the technological level of every innovation, classifying it as major, intermediate or minor depending on its location within the technological spectrum.

The IM was introduced as an organized catalogue of innovations for a given subsector. IM can be used as a source of information for technology management and a reference point for historical analysis and follow-up studies. Fort the purposes of this paper, the IM was the main information source for the construction of *II*, a tool that proved to be the pivotal point of the econometric model. Regarding the results derived directly from an analysis of the IM, the pressures on technological innovation in the firms necessarily lead to pressures of pursuing both organizational and marketing innovations. However, is in this area where less innovation is performed within the firms, and where less research is pursued by academics. Both issues required substantial efforts.

The second tool, *II*, is a way of summarizing both qualitative (technological level) and quantitative (frequency) properties of the innovations implemented in a particular firm. The *II* is an important step (indeed, the first approximation) towards measuring innovation in Colombian agribusiness firms. The *II* is computed from each subsector´s IM and it is specific to each company. Results from the analysis of the *II* are not surprising, as they show relatively low values for most of the surveyed firms. The analysis also shows that there are few innovative business leaders in each subsector. The main strength of the *II* is to be a proper measurement tool of innovation itself. *II* does not try to measure innovation via proxy variables such as patents or investment in R & D, which is a common practice in other sectors. The complexity and characteristics of the agricultural sector, based on biological products, asked for a new framework of analysis and careful thought in building *II*, particularly taking into account differences in the technological level and frequency of innovations.

II can be used as a dependent variable in a semi-logarithmic linear regression model. Three features are highlighted in this econometric model. First, the use of a linear regression model to estimate the determinants of innovation, contrasting with Probit or (ordered) Logit models used in previous studies. Second, the most influential determinants for the innovation in the four subsectors and regions analyzed. And finally, the explanatory power of our main exogenous variable, the transactional model used by the firm. The most interesting feature of the econometric model is its capability of performing multivariate analysis, which enables it to capture the complexities of the agricultural sector. This allows us to conclude that there are no ideal models of innovation that fit equally all subsectors and regions, yet there are certain common influential factors. This feature has an enormous impact on the design of policies for increasing innovation in each subsector. Some policies will work across the whole agricultural sector whereas others will have a more focused use, and will be designed exclusively for a given subsector.

Participation in Regional Networks of Innovation (PARTI) has a positive effect on innovation of firms in all the subsectors analyzed. However, it is usual that the coordination and cooperation between actors in the innovation system is an isolated practice, infrequent and usually not belonging to a structured policy. This finding emphasizes the need of addressing system failures, primarily because most of the sources of agricultural innovation do not belong to the agribusiness firm.

Regarding R & D, there is no doubt that its results are an important source of innovation. However, improvements in productivity and competitiveness depend on the effective introduction and mastery of its results in the firm. For the design of innovation and technology policies, it is important to point out that while R & D has a positive effect on innovation, its explanatory power depends strongly on other factors, these being specific to the company, to the subsectors and regions analyzed, always from certain business perspective.

The interest in exploring the influence of market transactions on corporate innovation relates directly to the issue of risk arising from the conditions of uncertainty inherent to farming. The central assumption is that reducing the associated uncertainty is a strong incentive for innovation, because otherwise the firm cannot appropriate the benefits of the investment. The results of the econometric model confirm that since there is a positive effect on the *II* level in all subsectors when firms use transactional models that differ from the classic market. In these models the firm usually signs sale contracts or integrates vertically, or uses a combination of both strategies. The companies engaged with these models show significantly higher *II* than those that use traditional transactional models. Knowledge also flows through contracts between the parties. The fundamental problem lies in the fact that actors in the agricultural innovation system have difficulties recognizing that organizational innovations are as important as technical innovations to move forward the firms.

Further developments of this methodology are possible. It should be applied to other agricultural and even industrial subsectors, to evaluate its performance in such scenarios. It is also interesting to study the dynamics of innovations for the chosen subsectors, repeating a similar survey every three to five years. Such development will allow a panel data analysis.

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