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Knowledge flows and linkage with universities: the vision of Mexican farmers

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Abstract

This paper is about the linkage between academia and the productive sector in agriculture, focusing on the farmers' point of view regarding this linkage. It also explores another dimension of knowledge transfer: the links that farmers establish with their peers to share the knowledge they acquire. Two research questions guided this study: (1) What characteristics influence the propensity of a farmer to engage in direct links with researchers? and (2) What characteristics influence the propensity of a farmer to share (transfer) knowledge with other farmers? This paper is based on original micro data obtained from a survey of Mexican farmers in 2011. The Mexican case is interesting for different reasons: it is a large country with large scientific capacities in the agricultural sciences; there is a large number of small farmers living in rural areas—both commercial and subsistence, and agro exports make a contribution to the export structure. Hence, more knowledge flows are needed for the development process. The research questions are approached through a model with a binary dependent variable to analyse the variables that explain the likelihood that a farmer establishes links directly with researchers, and a model with a multinomial distribution in order to observe the determinants of knowledge transfers made by farmers among their peers. The main finding is that training, participation in farmer organisations and the geographical location matter to explain the probability that a farmer establishes links with researchers. Concerning to the propensity of knowledge sharing with other farmers, belonging to organizations that include a variety of agents related to the innovation process and a set of idiosyncratic factors specific to the region (e.g. a more communal type of culture) are relevant for this matter.

Keywords: University-farmers links, Knowledge transfer, Innovation, Agricultural sector, Farmers, Mexico

Introduction

According to the innovation system approach, innovation includes a variety of agents, interactions and multidirectional knowledge flows. In the case of the agricultural sector, two type of links are relevant for the innovation process: links between researchers and farmers associated with knowledge generation and application to productive ends, and knowledge sharing (transfer) between farmers associated with a broader dissemination of that knowledge between farmers.

There is a broad literature on university-industry linkage that have explored the drivers of those interactions from the firms' perspective (Laursen and Salter 2004; Eom and

Lee 2010; Torres et al. 2011; Maietta 2015; Dalmarco et al. 2015), from the researchers' perspective (Boardman and Ponomariov 2009; Perkmann et al. 2013), or from both perspectives (Arza and Vazquez 2010; De Fuentes and Dutrénit 2012; García et al. 2015; Arza et al. 2015). Studies analysing the drivers of university-industry linkage from the firms' perspective have found that structural and behavioural factors are the most important drivers of interaction. Structural factors include the firm's age, size, sector and context (Laursen and Salter 2004; Hanel and St-Pierre 2006; Segarra-Blasco and Arauzo-Carod 2008; De Fuentes and Dutrénit 2012; Dutrénit and Arza 2015). Behavioural factors include human resources and type and intensity of R&D activities performed by the firms (Laursen and Salter 2004; Eom and Lee 2010; Torres et al. 2011). A recent empirical research line has explored the role of geographic proximity for university-industry linkage, and highlighted the importance of the location of high quality universities in the region (Broström 2010; Laursen et al. 2011; De Fuentes and Dutrénit 2016). In contrast, this literature has barely explored this linkage in the case of the agricultural sector, or has focused on networks with established agribusiness more than farmers in a broad sense (Stefano 2012).

The literature on the linkage between researchers and farmers is limited and disperse, as it has followed many lines of enquiry. Based on the mainstream literature on university-productive sector linkage, Rivera et al. (2011) focused on the researchers' point of view regarding links in the case of the Mexican agriculture sector. From the argument that universities should be involved in community engagement, Ssemwanga (2013) discusses some channels of interaction between universities and agribusiness, mostly related to the formation of human resources, in a case study of Uganda. Zdravkovic (2014) documents a project of generation of agribusiness incubators by universities and research centres in five African countries, as a way of strengthening university-farmers partnerships and also educational programs. Some authors have explored the role of extension as an intermediary between research and farmer linkage (Swanson 1997; Rathore et al. 2008; Adesoji and Tunde 2012).

Other literature has explored more systematically the technological behaviour of farmers but has approached issues largely based on extension and adoption (Foster and Rosenzweig 1995; Conley and Udry 2000; Bandiera and Rasul 2002) instead of knowledge flow with researchers or amongst farmers. Some authors have explored technology transfer trying to integrate both vertical and horizontal links that farmers establish (Gonsalves et al. 2006; Mashavave et al. 2012). Concerning to knowledge sharing among farmers, Mashavave et al. (2012) explore the connectedness between small farmers, through social interactions, to improve the access and sharing of technology, and specifically focus on the mechanism of learning alliances. More recently, issues related to social capital have occupied the interest of researchers and practitioners to understand the exchange of knowledge among farmers (Teilmann 2012; del Real Navarro 2013; Gómez-Limón et al. 2014).

The introduction of an innovation system approach has opened other lines of research related to how farmers innovate and how they interact for innovation (Ekboir 2003; Ekboir et al. 2009; Hall et al. 2010; Christoplos 2010), as well as the role that intermediate institutions play (Klerkx et al. 2009; Kilelu et al. 2011; Dutrénit et al. 2012). Overall this literature recognises different factors that affect the linkage and then knowledge flows in the sector, such as farmers' age, education level, training, organisation and networking.

This paper primarily focuses on the academia-productive sector linkage in the agriculture sector. It concentrates on the farmers' point of view concerning to linkage and knowledge flows. The aim is to analyse the drivers of farmers' behaviour regarding linkage with universities. In addition, this paper explores a second aspect of knowledge flows by farmers: the sharing (transfer) of that knowledge to others farmers. Hence, this involves two dimensions: (1) the relationship between farmers and researchers, and (2) the relationship between farmers on the basis of the knowledge they acquired. Consequently, this paper focuses on two research questions: (1) What characteristics influence the propensity of a farmer to engage in direct links with researchers? and (2) What characteristics influence the propensity of a farmer to share (transfer) knowledge with other farmers?

This paper explores these questions in the Mexican case. Particular attention is given to explore whether education, training, and organisation are important drivers of knowledge transference in the agricultural sector in this country. In addition, due to the heterogeneity of the Mexican regions in cultural, institutional and economic terms (Esquivel 2000; Martínez 2016), we also explore the geographical location of the farmers.[1]

This paper is based on original micro data obtained through a survey of Mexican farmers in 2011. We approach the questions through two stages. The first stage uses a model with a binary dependent variable to analyse the variables that explain the likelihood that a farmer establishes links directly with researchers. In a second stage, we estimate a model with a multinomial distribution in order to observe the variables that explain the likelihood of knowledge transfer made by farmers among their peers.

After this introduction, next section explores related literature on linkage and transference in the agriculture sector. "Methods" section describes the strategy for data gathering and the methodology used. "Results and Discussion" section presents and discusses the empirical evidence, and "Conclusions" section concludes.

Background

The innovation process is a complex one, whose success requires the participation and interaction of different agents within innovation systems (Lundvall 1992, 2007; Nelson 1993; OECD 2012). The success of innovation systems depends not only on the individual capacity of the productive agents, but also on the capability of these agents to absorb the experience and knowledge of others, such as universities, research organizations and government agencies. It also depends on how they interact to generate and transfer knowledge. Thus, interaction and flow of information and knowledge among agents of the system is a central theme. Complex systems approaches have shown that agents act in parallel and react to what others are doing in an unpredictable and unplanned manner. In this line, the individual agents are grouped according to spontaneously specific patterns (e.g. self-organizing), which feeds the system (Holland 1995). These theoretical

[1] Mexico is divided into eight regions, emerging from the combination of natural and historical-cultural (forms of social and economic organization) factors: Northwest, Northeast, West, East, North-Centre, South-Centre, Southeast and Southwest.

advances have helped to explain the specifics of the innovation process in the agricultural sector.

According to the innovation system approach, three basic agents that are involved in the innovation process are universities and research organizations (generators of knowledge), firms/producers (user of knowledge and developers of innovations) and innovation intermediary organizations (articulators of the agents).

Innovations in the agricultural sector are the result of the incorporation of new knowledge and technologies related to new or improved varieties of seeds, tissues, vaccines, equipment, and cultivation and breeding techniques, which are introduced in different stages of production, processing and marketing. They also include the application of quality protocols, management improvements and access to new markets and products (Pomareda and Hartwich 2006). From the point of view of sectoral dynamics, it is clear that the heterogeneity of the structures, farmers capabilities, market dynamics and ways of marketing products, and the very diversity of animal and plant products require thinking about different ways of knowledge generation and innovation sources from those observed in the industry.

The agriculture sector is associated with science-based industries (e.g. pesticides and seeds), scale-intensive industries (e.g. fertilizers), the segment of specialized suppliers (e.g. farm equipment) and the segment dominated by the suppliers of machinery and inputs (e.g. chemicals) (Possas et al. 1996). The production and supply contracts include quality standards, sanitary specifications, and features of packaging, among others. For many farmers all this implies investment in machinery and equipment, use of specialized services, standardization of practices, incorporation of new techniques and precision agriculture (Echenique et al. 2007). That is, increasing access to knowledge and new technologies of production and marketing is important for farmers' survival. Innovation is at the core of all this process.

Different empirical studies have shown that knowledge cannot be easily generated in research organizations and transferred to farmers through extension services and development projects (Swanson 1997; Rathore et al. 2008; Swanson and Rajalahti 2010; Adesoji and Tunde 2012; OCDE 2012). In response, new forms have emerged to manage the process of knowledge creation and sharing (transfer). They focus on new dynamics such as participation, community engagement, collaboration and joint learning between farmers and others, which contribute to the development and dissemination of knowledge beyond the traditional farmer-extension link (Hartwich et al. 2007; Iwanaga 2012). In this line, recently, more attention is given to the idea of a greater involvement of farmers in the knowledge generation process (MacMillan and Benton 2014).

In the traditional approach, which has followed a linear model, technical change occurs along a process that begins with basic research, is followed by the transfer of research, and ends with the adoption by farmers. Hence, this model is dominated by unidirectional flows, which are mediated by markets. In contrast, in an approach based on the concept of innovation systems, technological development and adoption are social phenomena where agents interact in various ways and create multiple streams of information and knowledge in various directions. These agents (e.g. public research and extension systems, innovative farmers, businesses, foreign research institutions) form networks that are developed together with the technologies they create (Ekboir 2002).

Network effects are important for individual decision-making, and in the particular context of agricultural innovations, farmers tend to share information and learn from each other (Bandiera and Rasul 2002; Mashavave et al. 2012).

Hence, in contrast with the linear approach, the use of the innovation system perspective places the links at the centre of the analysis. Success depends on how effectively farmers builds links and partnerships with a wider set of agents from academia, private sector and civil society, as well as between farmers themselves (World Bank 2006; Hall et al. 2011; Hall 2012). Currently, customers also have become important agents in the transformation of the agricultural sector. As farmers face today's challenges emerging from the speed of changes in agricultural markets, associated with changing consumer demands and trade liberalisation, new partnerships, new rules and regulations, and new forms of innovation are required. In fact, the focus of the framework has moved from Technology Transfer, to Agricultural Knowledge and Information Systems (AKIS) to Agricultural Innovation Systems (AIS) (World Bank 2006; Hall 2009). Moreover, as argued by McMahon (2012), more than a narrow AKIS focus, an innovation system perspective is needed.

The dimensions of organization and partnership help to connect individuals and institutions working on similar issues, improving access to information and knowledge and allowing access to improved methods and tools. Likewise, attitudes change from competition to collaboration, because the joint work promotes the ability to meet their needs and receive additional funding. These changes contribute to the development of a more efficient innovation system (CIAT 2010).

To the extent that there are many agents related to innovation in the sector, this process, particularly among small producers, requires the existence of farmers' individual capacities and the development of learning processes from a wide variety of agents -private, public and civil society, including technology and knowledge suppliers, farmers, financial institutions, NGOs, intermediate organisations, and other government support agencies (Hartwich et al. 2007; Hall 2012).

These processes occur more consistently when farmers have more training and are organized, and they are often based on informal relationships. The interaction in networks is important for individual decisions, but also helps farmers to share information and to learn from each other (Foster and Rosenzweig 1995; Conley and Udry 2000; Mashavave et al. 2012). In this direction, two issues have recently acquired more interest. The first refers to building trust to enable farmers to engage with their peers and then strengthen production and knowledge networks (Sligo and Massey 2007; Thorsøe and Kjeldsen 2016). The second concerns to the building of social capital, a complex and multidimensional concept, which is understood as the set of norms, values, attitudes and beliefs shared that promotes cooperation between individuals in a community (Ostrom 1999; Gómez-Limón et al. 2014). The accumulation of social capital is seen as a factor contributing to the development of communities in rural areas.

Technology transfer is an old issue in the sector. It has been conceived as the flow of knowledge through an orderly and systematic method of transmission of technological and structured knowledge from research organisations to farmers (Gonsalves et al. 2006; Schmidt Bassi et al. 2014). This approach is essentially about a process of transferring knowledge from researchers to producers. It includes three sub processes: technology production, delivery of technologies to farmers, and monitoring and evaluating the use of technologies (adoption). But the transfer process may include a step farmer–farmer; the latter process is critical to the success of the overall production cycle. At this level, knowledge is constructed through the process of learning by doing, learning by discovery, learning from others and learning from mistakes (Schulz 2002). The process of technology transfer between peers, where the priority is in building the collective knowledge, has been successful in achieving significant changes in improving farms. In these models the producer brings expertise, analyses specific situations, compare reviews and makes decisions based on what they learned. Some of the most widely used techniques are: Participatory Rural Appraisal, Farmer Participatory Research and Farmer Field Schools (Ashby et al. 1987; Haverkort et al. 1988; Hagmann et al. 2002; Gonsalves et al. 2006).

This paper is based on an innovation system perspective, and explores knowledge links that farmers build with universities and research centres. It also analyses other links they build with their peers -other farmers. This is a somewhat different approach those in the literature on technology transfer or university-industry linkage.

In addition, the reviewed literature suggests that several characteristics of the farmers affect the linking process, such as age, education, organization and networking. Training has positive effects on the ability to disseminate knowledge within groups. More training means more experience, members will have more confidence to train others and will be more likely than others to come for advice (Davis et al. 2004). Several studies have reported that technology adoption occurs more effectively when there is training and demonstration of the new procedures (Biggs 1997; Nesbitt and Samuel 2006; Torres et al. 2013). Training is also seen as a factor that favours social capital (Gómez-Limón et al. 2014).

Farmers' age is a factor to be taken into account, especially to promote technological change processes and introduce new activities (Biggs 1997). In general, younger farmers hold a better formal education than older ones (Vernooy et al. 2003). Gómez-Limón et al. (2014) also found a positive relationship between age and the accumulation of social capital. Farmers' level of education is also an important factor in the knowledge transfer process; farmers with higher education have access to brochures and technical journals with agricultural information and they are more able to absorb knowledge than those with less education. In other words, human capital also matters.

The evidence suggests that farmers' groups with greater homogeneity among its members are better disseminators of knowledge, because this homogeneity increases the understanding and unity, members also have interests, languages, goals, history, culture and common goals (Davis et al. 2004); in this sense memberships to farmers' associations matter. Belonging to social networks and proximity to the sources of knowledge play an important role in sharing knowledge and contribute to the diffusion of innovations (Mashavave et al. 2012).

The increasing complexity of knowledge development, transfer and adoption, and the multiple factors affecting the linking processes of both researchers and farmers, and among farmers, suggest the need for changes in science, technology and innovation policy, from the linear approach to a systemic approach.

Methods

The aim of this paper is to explore the drivers of farmers' behaviour regarding linkage with universities, and also the propensity to share (transfer) knowledge to others farmers. Hence, two different processes are relevant for this analysis: a) transfer from sources of knowledge generation (e.g. universities or public research institutes) to the farmers, and b) dissemination that occurs among the farmers themselves. The methodology considers both processes right from the data collection, which was based on questionnaires specifically designed to explore each one. The econometric estimation was also designed according to their specificities.

Data collection and sample characteristics

This paper is based on micro level data of Mexican farmers collected from three sources of information: (1) The national system of research and technology transfer for sustainable rural development (Sistema Nacional de Investigación y Transferencia Tecnológica para el desarrollo rural sustentable), based on the product-systems,[2] (2) the Produce Foundations,[3] and (3) a list of farmers related to a group of surveyed researchers in a previous study of the authors of this paper (see Rivera et al. 2011). Our population of interest is integrated by commercial and organized farmers of the agricultural sector in Mexico; therefore, subsistence farmers are excluded from the database.

As mentioned above, there are at least two types of knowledge flows where farmers are key actors: (a) the transmission of knowledge through direct links between farmers and researchers, and (b) the sharing (transfer) of that knowledge among farmers themselves. Therefore, to account for this segmentation, two different questionnaires were applied:

1. This is intended for those farmers that have links with researchers. The objective of this questionnaire is to identify different forms of interaction between researchers and producers and, additionally, to understand if those producers transfer the acquired knowledge to other farmers. A total of 200 observations were obtained (Profile 1).
2. This is focused on those farmers without direct links with researchers, and aims to explore how knowledge is transmitted to them from other farmers. A total of 207 observations were obtained (Profile 2).

Both questionnaires collected information on individual characteristics of farmers (age, training, education, location). The information is fully compatible between the two questionnaires. Data coming from questionnaire 2, which refers to farmers without links with researchers, is used as a control group. Table 1 shows some descriptive statistics that allow us to make an initial analysis of the sample characteristics.

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[2] The Product System is defined by the law as "…the set of elements and agents of concurrent agricultural and livestock production processes, including the supply of technical equipment, supplies and services for primary production, stockpiling, processing, distribution and marketing…" (Sustainable Rural Development Law, Art. 3o, fracc. XXXI 2001). SNITT played a key role to articulate the Product Systems all over the country.

[3] The PF are farmer-managed foundations that manage public resources for agricultural research, extension and innovation projects. There are 32 PF, one in each Mexican state, and a national coordinating body (COFUPRO in its Spanish acronym). Each PF is governed by a President, who is a leading farmer, and a board of farmers, leaders of farmers' associations and representatives from the federal and state governments. A professional manager directs operations. COFUPRO, in turn, has a board composed of Presidents of some PF and a professional management team.

Table 1 Descriptive statistics

Variable	Profile 1	Profile 2
Age	50.9	52.3
Elementary studies (%)	33.5	48.5
University studies (%)	29.2	21.5
Belongs to product-systems (%)	59.0	37.0
Belongs to farmers associations (%)	72.2	49.0
Fruits crop (%)	54.7	57.5
Grains and cereals crop (%)	29.7	29.0
Vegetables crop (%)	15.6	13.5
South region (%)	12.7	11.5
West-Centre region (%)	35.8	48.0
Centre region (%)	16.5	20.5
North region (%)	34.9	20.0
Have received training in the last 3 years (%)	89.1	42.0

The average age in both samples is close to 50 years. However, there are differences between Profiles 1 and 2 with respect to level of education: while nearly 50 % of the sample of farmers for the Profile 2 has studied only elementary school, this number drops to 33 % for Profile 1. In the same line, farmers in Profile 1 with higher education conform nearly 30 % of the sample while in Profile 2 only 21 %. The variable that most clearly differentiates both profiles is training: while about 89 % of the members of Profile 1 have taken training courses in the last 3 years, only about 42 % have done so in Profile 2. The data indicates that both farmers' profiles are located in all the country's regions. However, Profile 1 tends to have a higher presence in the West-Centre (36 %) and the North (35 %), meanwhile Profile 2 has a predominant location in the West-Centre (48 %).

Dependent and independent variables

In the econometric section ("Results and Discussion" section), the first stage uses a binary outcome model to analyse those variables that explain the likelihood that a farmer establishes links directly with researchers. In the second stage, a model with dependent variable with a multinomial distribution is estimated in order to observe the drivers of knowledge transfer made by farmers among their peers. The following summarizes the information on the main variables to be used in both stages of estimation.

Dependent variables

Stage 1: Links between researchers and farmers (*linkages*). This is a dummy variable indicating whether the farmer is directly linked to researchers.

Stage 2: Type of knowledge transfers between farmers *(transference)*. This is a categorical variable indicating the type of knowledge transfers used by farmers to share between themselves. The construction of this variable is by far more complex than that developed in the previous stage, and involves the use of multivariate techniques, in particular, cluster analysis.

Cluster analysis is a multivariate technique to classify objects on the basis of their common properties, resulting in groups that are internally homogeneous but maximizes

Table 2 Basic statistics of the clusters

Variable	Cluster transference 1	Cluster transference 2	Cluster transference 3	Cluster transference 4	Total
Age (years)	51.80	50.34	51.00	49.71	50.9
Elementary studies (%)	40.35	25.58	30.91	28.57	33.5
University studies	12.28	37.21	30.91	50.00	29.2
Belongs to product-systems (%)	61.40	83.72	47.27	50.00	59.0
Belongs to farmers associations (%)	82.46	74.42	65.45	78.57	72.2
Fruits crop (%)	49.12	30.23	70.91	61.90	54.7
Grains and cereals crop (%)	22.81	58.14	21.82	26.19	29.7
Vegetables crop (%)	28.07	11.63	7.27	11.90	15.6
South region	1.75	11.63	29.09	7.14	12.7
North region	45.61	18.60	20.00	52.38	34.9

differences among them. In order to cluster our data, we applied the Two–Step Clustering procedure available in SPSS (release 15.0). This procedure has all the advantages of traditional clustering methods (hierarchical or non-hierarchical procedures), with the added benefits of handling categorical and continuous variables and automatic selection of the number of clusters.

The farmers in our data are classified using questions from questionnaire 1,[4] which explored the knowledge transfer channels used by farmers and whom they transferred it to. This resulted in four clusters. Tables 2 and 3 summarizes the basic statistics of the clusters.

Cluster transference 1: Transfers mainly through informal relationships and mostly to relatives, friends and neighbours.
Cluster transference 2: Net transferee. Transfers occur through informal relationships but also using formal mechanisms (such as brochures); it includes the leading diffusers of knowledge, and it is a connector to the academy.
Cluster transference 3: The least dynamic. It transfers only through informal relationships with relatives and friends.
Cluster transference 4: Transfer dynamics is similar to cluster 2, but less dynamic.

Independent variables

As noted above, the objective of this paper is to study the determinants of linkage. In particular it seeks to explore the importance of the level of education, training and organization of farmers in the dissemination of knowledge. These will be, therefore, the main independent variables of our analysis in both stages.

[4] This questionnaire is designed to know if the farmers on our database link to researchers in order to acquire knowledge, if they transfer it to other producers, and the channels they use to do it. Questions like the following were applied: "How do you spread the knowledge acquired through researchers contact to other farmers?", "To whom do you share the knowledge acquired through researchers contact?". Additionally, the intensity of the answers is measured through a Likert scale.

Table 3 Importance of knowledge transfer by farmers to other agents (%)

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Relatives	95.24	96.23	59.68	76.92
Friends	98.41	100.00	70.97	88.46
Neighbours	93.65	100.00	40.32	71.15
Community leader	34.92	83.02	11.29	32.69
Members of the product-system	58.73	96.23	20.97	71.15
Members of the producers' association	80.95	96.23	53.23	73.08
Researchers	34.92	64.15	4.84	55.77

Education This variable considers the highest level of education of farmers in both samples. One would expect a positive relationship between level of education and links with researchers.

Elementary is a dummy variable equal 1 if the farmer has at most completed primary education, 0 if the farmer has an education level higher than primary education.

University is a dummy variable equal to 1 if the farmer has at least completed college education (bachelor degree o postgraduate), 0 if the farmer has a lower level of education.

Training *Training* indicates the intensity with which farmers have been trained. It indicates the number of times in the last 3 years that farmers have participated in courses or field days. One would expect a positive relationship between training and links with researchers, and also between training and sharing of knowledge amongst farmers.

ln_training is a logarithmic transformation of *training*,[5] and explores the possible relationship between *training* and the logarithmic likelihood that a farmer establishes links with researchers in the model corresponding to stage 1.

Organization This variable is a proxy on the form of farmers' organization. One would expect a positive relationship between organization and links to researchers, and organization and sharing among farmers. There are two variables related to the form of organization:

Product-Sistems is a dummy variable with a value of 1 if the farmer participates in a product system, 0 otherwise.

Farmers associations is a dummy variable with a value of 1 if it belongs to an association of producers, 0 otherwise.

Other control variables

Age (age) The farmer's age in years. We would expect the younger farmers to be linked more to researchers than those of an older age. To control for a possible quadratic relationship we introduce the square of age (*sqr_age*).

[5] Actually *ln_training* is the natural logarithm of training plus one. The addition of one seeks to avoid the problems arising from the zero value.

Size (size) It is measured by the number of hectares cultivated. It is a proxy to the income and economic capacity of producers.

Crop ($crop_i$) These variables indicate the main type of crop. The type of crop may be related to the type of farmers' organization, as there is a product-system by crop type and even specific product type.

crop1 is a binary dummy variable with value 1 if the farmer cultivates fruits.
crop2 is a binary dummy variable with value 1 if the farmer cultivates grains and cereals.
crop3 is a binary dummy variable with value 1 if the farmer cultivates vegetables.

In the regressions, the omitted variable is *crop2*.

Region (region) These variables represent cultural and institutional characteristics of the region where the farmer is located.
South is a binary dummy variable with value 1 if the farmer is located in the southern region of the country.
West_centre is a binary dummy variable with value 1 if the farmer is located in the west-centre.
Centre is a binary dummy variable with value 1 if the farmer is located in the central region.
North is a binary dummy variable with value 1 if the farmer is located in the northern region.
The northern region is considered as the comparison variable.

Rainfed lands (temporal) This is a dummy variable indicating whether the producer uses only rainfed lands. It is thought that this variable may function as a proxy to the lack of technology, taking into account that the work on irrigated land or greenhouse implies a greater complexity of skills, and requires more investment and use of technology.

Time (time) This is a variable that is used only in the model of stage 2. It indicates the number of years that the farmer has been linked to the researcher.

The main statistics of the variables of Stage I and Stage II are presented in the "Appendices 1 and 2".

Results and Discussion

Stage I: Logit model of the determinants of linking

As mentioned in the previous section, the econometric estimation of stage I uses a categorical binary dependent variable (*linkages*). In this case, an ordinary least square model (OLS) is not the most suitable option to fit it. As Baum (2006: 248) mentioned, even whether it is possible to estimate the model with OLS, some problems would appear: it is likely to produce point predictions outside the unit interval, and the error could not satisfy the assumption of homoscedasticity. In this case, the use of nonlinear binary response models, like the logit one used in this work,[6] is suggested. A logit model overcomes this problem by using a logistic distribution that ensures that the estimated responses probabilities are strictly between zero and one. Additionally, since nonlinear binary response models are usually calculated using maximum likelihood estimations and because these are based on the distribution of y given x, the heteroskedasticy is automatically accounted for (Wooldridge 2009: 578).

Table 4 contains different specifications of the model. The specifications 1 and 2 are essentially the same, involving all the main explanatory variables, and most of the control variables. The only difference between these two specifications is the functional relationship between *training* and *linkages*: while model 1 assumes a linear relationship, model 2 considers a logarithmic function (ln_training), where an increase in *training* always increases the probability that a farmer establishes links with researchers, even though their marginal impact is decreasing. It is observed that the results in both specifications are very similar, but the significance of *ln_training* is greater than that of *training*. Additionally the value of the pseudo R^2 and chi^2 is greater in model 2 compared to model 1. This would suggest that model 2 is a better specification than model 1. Therefore, unless otherwise stated, subsequent analysis is based on the specification of model 2.

As expected, there is a positive and highly significant relationship between *ln_training* and *linkages*. Thus, on average, the greater the continuity of training of a farmer, the greater the chance that he/she establishes links to researchers. However, and as counter-intuitive, we did not find a direct relationship between the academic level of the farmer and the likelihood of linking with researchers. In other words, our estimate suggests that the likelihood of establishing interactions with researchers is the same, whether the farmer has only basic education (elementary) or higher education. This result is reinforced if we observe the outcomes of model 4, which has a similar specification as model 2, with the only difference that instead of elementary studies, it estimates the impact of having a college degree on the probability of linking to researchers. Nevertheless the result is similar: the probability of linking does not increase if farmers are university graduates.

Even though a positive and significant relationship was not found, it does not mean that the education level does not affect at all the probability of linking. We argue that the education level may affect only indirectly the likelihood of engaging with researchers. Estimations previously made by the authors[7] show that both high school education and higher education are significant determinants of the intensity with which the farmer is trained (*training*). These results seem to indicate that higher levels of education are associated with increased training. However, to be linked, education is not enough, it requires both the opportunity and the desire to interact.

With regard to organizations, the evidence shows that belonging to a product-system (a structure/network that integrates the set of agents of concurrent processes)[8] or a farmers' association (by crop, location, etc.) impact the probability that a farmer

[6] Tests were also conducted using probit models; the results are essentially very similar.

[7] These estimations can be obtained from the authors.

[8] The Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food put the Product-System at the centre of innovation policy with the aim of fostering competitiveness along the value chain. In this sense, belonging to a Product-System is important to access funds. Product-Systems also constitute a network for production and commercialization.

Table 4 Stage 1: Regression models (logit) Independent variable: *linkages*

	Model 1	Model 2	Model 3	Model 4
Elementary	−0.387	−0.378	−0.352	
	−1.52	−1.46	−1.39	
University				−0.019
				−0.07
Training	0.168			
	(4.17)***			
ln_training		0.737	0.735	0.755
		(5.32)***	(5.42)***	(5.39)***
Product-system	0.813	0.751	0.674	0.768
	(3.32)***	(3.01)***	(2.81)***	(3.08)***
Farmers' associations	0.623	0.572	0.51	0.626
	(2.49)**	(2.25)**	(2.10)**	(2.47)**
Age	0.122	0.135	−0.011	0.127
	(2.06)**	(2.24)**	−1.1	(2.13)**
sqr_age	−0.001	−0.001		−0.001
	(2.27)**	(2.42)**		(2.40)**
Size	−0.001	−0.001		−0.001
	−0.59	−0.68		−0.52
Crop1	−0.378	−0.356		−0.358
	−1.31	−1.22		−1.23
Crop2	0.018	0.035		0.032
	−0.05	−0.09		−0.08
South	−0.921	−1.034	−0.693	−1.051
	(2.11)**	(2.33)**	(1.78)*	(2.38)**
West_centre	−1.364	−1.417	−1.228	−1.383
	(4.32)***	(4.41)***	(4.07)***	(4.31)***
Centre	−1.666	−1.713	−1.32	−1.723
	(4.23)***	(4.26)***	(3.75)***	(4.28)***
Temporal	0.44	0.443		0.441
	−1.48	−1.46		−1.46
Constant	−2.438	−2.915	0.354	−2.792
	−1.62	(1.91)*	−0.64	(1.83)*
Observations	412	412	412	412
LR $Chi^2(8)$	96.41	105.03	92.97	102.91
Pseudo R^2	0.1689	0.184	0.1629	0.1803

Absolute value of z statistics in parentheses

* Significant at 10 %; ** Significant at 5 %; *** Significant at 1 %

establishes links with researchers. It means that both types of organisation favour the probability of linking to researchers; in other words, if farmers are organised they tend to link with researchers more than if they work individually.

The analysis of other control variables also provides interesting results. Similarly to the Mincerian human capital equation (Mincer 1974), there is evidence of a quadratic relationship between age and the likelihood of establishing links. Thus, the results seem to indicate that the probability of linking increases with age but with decreasing effects.

Counter intuitively, it is observed that the probability of linking is neither related to the type of land cultivated (*temporal*) nor with the technology involved in it. Thus there seems to be no significant difference in the probability of linking when cultivated on irrigated land, greenhouse or rainfed lands. Related to the previous variable and also contrary to expectations, neither the number of hectares (*size*) nor the type of crop cultivated (*crop*) appear to influence the probability of linking.

Indeed, what does have a significant effect is the variable that involves regions where the farmer is geographically located. The results clearly show that there is a negative and highly significant relationship between belonging to a different region to the North and the probability of linking to researchers. Variables indicating the geographic location of the farmer involve a series of idiosyncratic characteristics and are therefore difficult to interpret within the framework we are using. However, this deserves some comments. The agricultural sector in Mexico has very advanced farmers, many of them are located in the North (including North-East and North-West). This is the most developed industrial region, in which industrial skills are broadly disseminated. A large part of agroindustrial firms are also placed here. It is also a region with a more established business culture and, furthermore, it is the most developed region in the country. The result may indicate that factors such as institutional, cultural perspectives and business behaviour that exist in the environment may influence the probability that a farmer establishes links with researchers.

Stage 2. Multinomial model on the transference dynamics between farmers

Stage 2 estimates the effect of the main explanatory variables on the dynamics of knowledge transfer among farmers. The dependent variable (*transference i*) can fall into one of four categories, whose characteristics are described in "Methods" section, and therefore must be multinomial distributed, just as binary data must be Bernoulli or binomial distributed. The estimation is, broadly speaking, a generalization of the method used for binary outcome models, and the coefficients are interpreted with respect to a chosen category (Cameron and Trivedi 2009: 498). In this work, the base category is *transference 2*: the most dynamic cluster in terms of knowledge transfer, according to the classification based on their characteristics of "Dependent and independent variables" section. Table 5 presents the results of the Multinomial model.

Transference 1 versus transference 2

These are the categories that are accepted as more dynamic relative to knowledge transfer (see description of the clusters in "Dependent and independent variables" section). The fundamental difference is that farmers within category 1, tend to transfer to other farmers in a less formal way than those of category 2. It can be noted that the latter category actively transferred both to farmers and to researchers.

Having a university degree (*university*) affects the probability of belonging to the base category (*transference 2*) with respect to category 1 (*transference 1*). This would help to explain the fact that cluster 2 tends to transfer more formally and to farmers who are geographically more distant from them. Nevertheless previous regressions (not presented here) indicate that lower levels of education (primary, secondary, high school) do not affect the probability of belonging to one category or another. The type of organization to which farmers belong is another variable that is statistically significant. So while being part of a *farmers' association* increases the probability that the farmer belongs to Cluster 1, being part of a *product-system* affects the farmer's belonging to Cluster 2. As

Table 5 Multinomial model, predicted odd ratios

Variable	ln (T1/T2)	ln (T3/T2)	ln (T4/T2)
University	−1.73	−0.02	1.18
	0.006***	0.96	0.031**
Training	0.06	−0.06	−0.01
	0.26	0.31	0.90
Product-system	−1.66	−1.94	−1.17
	0.007***	0.001***	0.054*
Farmers' associations	1.15	0.01	0.17
	0.08**	0.98	0.79
South	−2.86	0.35	−2.07
	0.022**	0.67	0.028**
West_centre	−0.10	0.32	−2.12
	0.88	0.65	0.003***
Centre	−1.15	−0.12	−1.45
	0.14	0.89	0.069**
Time	−0.28	−0.21	−0.70
	0.34	0.48	0.03**
Crop1	1.92	1.98	1.86
	0.001***	0.001***	0.002***
Crop2	2.90	1.03	1.38
	0***	0.21	0.094*
_cons	0.43	0.93	1.84
	0.70	0.05	0.92

p value in parentheses

* Significant at 10 %; ** significant at 5 %; *** significant at 1 %

farmers' associations are integrated only by farmers, in contrast, a system-product is integrated by all the agents involved in different stages of the production process, including commercialization; hence, the result suggests that the interaction with a variety of agents, not only with farmers, encourages farmers to form part of the most dynamic cluster in terms of the transfer (Cluster 2).

Contrary to what was happening in the estimation of the determinants of the linkages with researchers (logit model), the variable *training* does not have impact on the types of knowledge transfer between farmers of any of the categories (*transference 1, 3, 4*) regarding the base category (*transference 2*). A review of the other control variables provides additional useful information for the analysis. It is very interesting that belonging to the South (respect to the North), a less developed region, increases the probability of being in category 2 (always compared to *transference 1*). This could be connected with the role that social relations and communal culture, which characterise this region, may play in the sharing of knowledge amongst farmers. Finally, both *fruits* and *vegetables* are more related to Cluster 1 that *grains and cereals* (closer to Cluster 2). Unfortunately, concerning crops we have no clear explanation for this result.

Transference 3 versus transference 2

Cluster 3 is the most difficult to analyse. Although in "Methods" section this cluster is clearly distinguished from others by being the least dynamic, two variables resulted significant to explain these differences: organization and type of crop. As in the previous case, belonging to a *product-system* affects the farmer belonging to cluster 2 relative to cluster 3. In contrast, belonging to a *farmers' association* has neither positive nor negative effect. In this case, again, the interaction with several agents has a positive impact on the dynamics of transfer between farmers (transference 2). The second variable that affects this relationship is the type of crop; *fruit* farmers tend to pertain to Cluster 3 in relation to Cluster 2, which houses the farmers of *grains and cereals* that are more dynamic. It can be said that to the extent that the farmer is more modern, he/she is more likely to innovate and to interact with other innovative producers. However, we found that in a more modern type of crop, as fruits, farmers tend to be more cautious and transfer less knowledge to other farmers. This could be explained by the argument that the most innovative farmers may not be interested in interacting with producers who are technologically behind and have lower capacities.

Transference 4 versus transference 2

Although, superficially, Cluster 2 and Cluster 4 may look similar, the estimation of the econometric model indicates that the characteristics of the groups differ: counter intuitively, having a college education (*university*) increases the probability of belonging to *transference 4* versus *transference 2*. Again, belonging to a product-system affects the inclusion of the farmer to *transference 2* with respect to *transference 4*.

Concerning the other control variables. An interesting fact is that belonging to any region other than the North (*south, central, west central*) decreases the probability of belonging to *transference 4*. In other words, belonging to the North increases the probability of belonging to *transference 4*.

This comparison of clusters raise an issue that had not been discusses above: the time length of the linkage between farmers and researchers affects the farmers' belonging to the clusters (and thus the type of transfer made to other farmers). Thus, the longer the time that farmers have linked to researchers, the higher the probability of belonging to Cluster 2, which is more dynamic in terms of knowledge transfer between farmers. Finally, as in previous cases, growing fruits and vegetables makes the probability of belonging to Cluster 4 increase in relation to Cluster 2.

Summing up, the evidence on this second stage of knowledge transference, amongst farmers, leads to an interesting conclusion: the main variables that affect the transfer between farmers are: the type of organization (product-system) and a set of idiosyncratic factors specific to the region. In this discussion, belonging to an organisation like the product-system, and then interacting with a variety of agents, favours a more dynamic profile of transfers, such as that of Cluster 2. Also belonging to the South, a region characterized by a more communal type of culture, where social capital related issues mediate market relationships, also favours this dynamism.

These results do not mean that education does not count at all. Education accounts by increasing the formality of the transfer process and expanding their range of extension. Indeed, a comparison between *transference* 1 and 2 shows that higher education (university) affects the belonging to Cluster 2 (consisting of the most dynamic transferors). However, this does not seem to be the determining variable of transfer. This can be seen in the comparison of Cluster 2 and 4. Cluster 4 consists of farmers located at the North, who tend to be more educated than in Cluster 2. However, Cluster 2 has more desirable properties of transfer than Cluster 4. So what makes the difference? It seems that the type of organization, the region where farmers are located (and its cultural, institutional and economic characteristics) and the length of the link time with researchers. That is, all elements pointing to social capital.

Conclusions

This paper has focused on the farmers' point of view regarding linkage and knowledge transfer, and explored the links that farmers established with researchers and other farmers. Two research questions guided this research: (1) What characteristics influence the propensity of farmers to engage in direct links with researchers?, and (2) What characteristics influence the propensity of farmers to share (transfer) knowledge with other farmers? Particular attention was given to explore whether education, training and organisation are important drivers of knowledge transference, as well as the influence of the geographical location of farmers on transference related activities. Hence, factors related to human and social capital were introduced into the analysis of the drivers of transference.

Concerning to the characteristics that influence the propensity of farmer to establish direct links with researchers we found that:

- The greater the continuity of the farmers in training activities, the greater the likelihood that they establish links with researchers. This result is in line with the argument that training is important for disseminating technologies within groups (Davis et al. 2004) and for technology adoption (Biggs 1997; Nesbitt and Samuel 2006; MacMillan and Benton 2014).
- We did not find a direct relationship between the level of education of the farmers and the likelihood of linking with researchers. In contrast, several authors highlight the importance of education in technology transfer and adoption processes (Biggs 1997; Vernooy et al. 2003). The education level was found important in studies on university-industry linkage in the manufacturing sector (Eom and Lee 2010; Torres et al. 2011). Previous estimations by the authors of this paper found an indirect relationship through training in the Mexican agriculture sector, based on a correlation between education and training.
- Participation of farmers in any type of farmers' organisation favours the probability of linking with researchers; in other words, if farmers are organised they tend to link with researchers more than if they work individually.
- The geographical location of farmers matters to explain the likelihood of linking with researchers; the North region, more developed than other Mexican regions, provides an adequate environment to link with researchers. This result may indicate that institutional factors, business behaviour and knowledge infrastructure that exist in the environment influence the probability that a farmer establishes links with researchers. Even though the location was found relevant for the manufacturing sector, authors tend to emphasise local knowledge infrastructure more than issues related to social behaviour (Boschma 2005; Abramovsky et al. 2007; Giuliani 2005; De Fuentes and Dutrénit 2016).

- Overall, it was found that behavioural factors are more important than structural factors, which differ from the finding in the manufacturing sector.

Concerning to the characteristics that influence the probability that a farmer chooses to transfer knowledge to other farmers, i.e. the dynamic of knowledge transfer, we found that:

- Belonging to organizations, which include a variety of agents related to the innovation process, favours a more dynamic profile of transfer, such as that observed in Cluster 2. These results on the importance of organisation confirm the arguments by Hartwich et al. (2007) and CIAT (2010), and also those about the importance of interaction in networks by other authors (Foster and Rosenzweig 1995; Conley and Udry 2000; Thorsøe and Kjeldsen 2016).
- A set of idiosyncratic factors specific to the region determines the dynamic of knowledge transfer between farmers. Rather than institutional factors and business behaviour, in this case cultural perspectives are more relevant. Belonging to the South, a region characterized by a more communal type of culture, seems to favour this dynamism. This region's features are in line with findings on the role of social capital and trust to explain farmers' technological behaviour (Sligo and Massey 2007; Gómez-Limón et al. 2014).
- The length of the link with researchers, with whom they also share knowledge, is also relevant for this matter.

These results have implications for policy. In order to foster university-farmers linkage and consequently promote the knowledge transfer amongst farmers, policies focused on farmers should include fostering training programs, supporting farmer' organisations and promoting links amongst other agents of the agro chain. Some programs should be oriented to the associations as a subject of support. In addition, as culture matters to share knowledge, support should not be limited to market mechanisms; in contrast some programs should be oriented to encourage the strengthening of social relations between farmers.

Our results are preliminary in nature; many of them point to the role of social capital in the agriculture sector. Future research is needed to explore in more detail different issues that emerge from this paper, such as the role of education for university-farmers linkage, the relationship between university-farmers linkage and different crops, the role of social capital for knowledge sharing amongst farmers, and the role of technology in these processes.

Authors' contributions

GD, RR and AOV participated in the conception and design, acquisition of data through a survey, data analysis and draft of the manuscript. RR ran the model. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Appendix 1: Variables, definition and main statistics, Stage 1

Variable	Definition	Mean	SD	Min	Max
Dependent variable					
linkages	Dummy = 1, the farmer is directly linked with researchers	0.5145	0.5003	0	1
Independent variables					
Age	Age	51.6	12.94	22	80
Sqr_age	Square of age	2830.07	1338.04	484	6400
Elementary	Dummy = 1, the farmer completed elementary school	0.4077	0.492	0	1
Training	Number of training courses over the past 3 years	2.63	3.88	0	30
ln_training	Log natural of training (training +1)	0.8516	0.9093	0	3.43
Product-Systems	Dummy = 1, belong to a product-system	0.483	0.5003	0	1
Farmers associations	Dummy = 1, belong to a farmers' association	0.6092	0.4885	0	1
Size	Number of hectares cultivated	34.25	94.12	0.25	800
Crop1	Dummy = 1, fruits are the main crop	0.5606	0.4969	0	1
Crop2	Dummy = 1, grains and cereals are the main crop				
Crop3	Dummy = 1, vegetables are the main crop	0.1456	0.3531	0	1
South	Dummy = 1, located in the South region	0.1213	0.3269	0	1
West_centre	Dummy = 1, located in the West centre region	0.4174	0.4937	0	1
Centre	Dummy = 1, located in the Centre region	0.1844	0.3883	0	1
North	Dummy = 1, located in the North region				
Temporal	Dummy = 1, use of rainfed lands	0.6043	0.4895	0	1

Appendix 2: Variables, definition and main statistics, Stage 2

Variable	Definition	Mean	SD	Min	Max
Dependent variable					
Transference	Four clusters				
Independent variables					
University	Dummy = 1, the farmer got a undergraduate degree	0.30	0.46	0.00	1.00
Training	Number of training courses over the past 3 years	3.77	4.24	0.00	20.00
Product-Sistems	Dummy = 1, belong to a product-system	0.59	0.49	0.00	1.00
Farmers associations	Dummy = 1, belong to a farmers' association	0.72	0.45	0.00	1.00
South	Dummy = 1, located in the South region	0.13	0.34	0.00	1.00
West_centre	Dummy = 1, located in the West centre region	0.37	0.48	0.00	1.00

Variable	Definition	Mean	SD	Min	Max
Centre	Dummy = 1, located in the Centre region	0.16	0.37	0.00	1.00
North	Dummy = 1, located in the North region	0.34	0.47	0.00	1.00
Time	number of years that the farmer has been linked to the researcher	1.99	0.92	0.00	3.00
Size	Number of hectares cultivated	41.02	104.21	0.25	800.00
Crop1	Dummy = 1, fruits are the main crop	0.54	0.50	0.00	1.00
Crop2	Dummy = 1, grains and cereals are the main crop	0.30	0.46	0.00	1.00
Crop3	Dummy = 1, vegetables are the main crop	0.16	0.37	0.00	1.00

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