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Industrial Ph.D. Programs for the Strengthening of the Industry's Production of Innovation in Colombia[1]

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ABSTRACT: Today's firms face a new global economy powered by knowledge rather than physical resources and natural raw materials. Universities are crucial actors in ensuring economic development, not only by training highly qualified human capital, but also by producing new knowledge with innovation potential. University–industry research collaborations (UICs) have been increasingly recognized as an innovation mode. Highly qualified people, mainly at Ph.D. level, are fundamental for the increase of the knowledge pool from which firms and society as a whole can benefit in terms of the production of innovation. The demand for more specialized researchers in business/industry has led to new versions of doctoral programs, such as Industrial Ph.D. Programs (IPPs), which are well-established in a number of countries. After using an analytical international and comparative education methodology, we have found that the cooperation with industry to develop Ph.D. programs in Colombia is relatively weak and requires to be enhanced. In this paper, we argue for the alignment of the so-called third academic mission of economic development with the traditional academic missions of teaching and research through the implementation of IPPs as a mechanism for strengthening the innovation process of firms and country's economic growth.

KEYWORDS: Higher education, research institutions, innovation, R&D, training.

PROGRAMAS DE DOCTORADO EN INDUSTRIA PARA EL FORTALECIMIENTO DE LA PRODUCCIÓN DE INNOVACIÓN INDUSTRIAL EN COLOMBIA

RESUMEN: La empresa actual se enfrenta una nueva economía global estimulada más por el conocimiento que por los recursos físicos y las materias primas de origen natural. En este escenario, las universidades son actores fundamentales para la consolidación del desarrollo económico, no sólo por su labor de formación de capital humano altamente cualificado, sino también por la producción de nuevo conocimiento con potencial innovador. Por ello, la relación universidad-industria es cada vez más reconocida como una forma de innovación en investigación. Profesionales altamente calificados, sobre todo a nivel de doctorado, son fundamentales para la expansión del acervo de conocimientos del cual pueden beneficiarse las empresas y la sociedad en términos de producción de innovación. La demanda de investigadores cada vez más especializados por parte de las empresas y la industria, ha dado lugar a nuevos programas de Doctorado en Industria, los cuales se encuentran ya consolidados en varios países. En este trabajo, luego de emplear una metodología comparativa y analítica en educación internacional, se concluye que la cooperación con el sector industrial para el desarrollo de programas de doctorado en Colombia es relativamente débil y que requiere de intervención. Adicionalmente, se presentan argumentos a favor de la alineación de la llamada "tercera misión académica" para el desarrollo económico con las misiones tradicionales de enseñanza e investigación, a través de la implementación de programas de Doctorado en Industria como mecanismo para el fortalecimiento del proceso de innovación de las empresas y el crecimiento económico del país.

PALABRAS CLAVE: Educación superior, institutos de investigación, innovación, I&D, formación.

PROGRAMAS DE DOUTORADO EM INDÚSTRIA PARA O FORTALECIMENTO DA PRODUÇÃO DE INOVAÇÃO INDUSTRIAL NA COLÔMBIA

RESUMO: A indústria atual enfrenta uma nova economia global estimulada mais pelo conhecimento do que pelos recursos físicos e as matérias-primas de origem natural. Nesse cenário, as universidades são atores fundamentais para a consolidação do desenvolvimento econômico, não somente por seu trabalho de formação de capital humano altamente qualificado, mas também pela produção de novo conhecimento com potencial inovador. Por isso, a relação universidade-indústria é cada vez mais reconhecida como uma forma de inovação em pesquisa. Profissionais altamente capacitados, principalmente com doutorado, são fundamentais para a expansão do acervo de conhecimentos do qual as empresas e a sociedade podem ser beneficiadas em termos de produção de inovação. A demanda de pesquisadores cada vez mais especializados por parte das empresas e da indústria tem dado lugar a novos programas de doutorado em indústria, os quais se encontram já consolidados em vários países. Neste trabalho, após empregar uma metodologia comparativa e analítica em educação internacional, conclui-se que a cooperação com o setor industrial para o desenvolvimento de programas de doutorado na Colômbia é relativamente fraca e requer intervenção. Além disso, apresentam-se argumentos a favor do alinhamento da chamada "terceira missão acadêmica" para o desenvolvimento econômico com as missões tradicionais de ensino e pesquisa, por meio da implantação de programas de doutorado em indústria como mecanismo para o fortalecimento do processo de inovação das empresas e para o crescimento econômico do país.

PALAVRAS-CHAVE: educação superior, institutos de pesquisa, inovação, P&D, formação.

LES PROGRAMMES DE DOCTORAT EN INDUSTRIE POUR RENFORCER LA PRODUCTION DE L'INNOVATION INDUSTRIELLE EN COLOMBIE

RÉSUMÉ: La société actuelle fait face à une nouvelle économie mondiale, stimulée davantage par la connaissance que par les ressources physiques et les matières premières d'origine naturelle. Dans ce scénario, les universités sont des acteurs cruciaux pour la consolidation du développement économique, non seulement par leur travail dans la formation de capital humain hautement qualifié, mais aussi par la production de nouvelles connaissances avec le potentiel de l'innovation. C'est ainsi comme la relation université-industrie est de plus en plus reconnue comme une forme d'innovation dans le domaine de la recherche. Des professionnels hautement qualifiés, en particulier ceux du niveau du doctorat, sont essentiels à l'expansion de la base de connaissances qui peut profiter aux entreprises et à la société en termes de production d'innovation. La demande de chercheurs de plus en plus spécialisés de la part des entreprises et de l'industrie a donné lieu à de nouveaux programmes de doctorat dans le domaine de l'industrie, qui sont déjà établis dans plusieurs pays. Dans cet article, après avoir employée une méthodologie comparative et analytique en éducation internationale, on conclut que la coopération avec l'industrie pour le développement de programmes de doctorat en Colombie est relativement faible et exige une intervention. En outre, on présente des arguments en faveur de l'alignement de la « troisième mission universitaire » pour le développement économique avec les missions traditionnelles d'enseignement et de recherche, à travers la mise en œuvre de programmes de doctorat dans l'industrie en tant que mécanismes pour renforcer le processus d'innovation des entreprises et la croissance économique du pays.

MOTS-CLÉ : Enseignement supérieur, instituts de recherche, innovation, I&D, formation.

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Introduction

A new global economy has emerged which is primarily based on knowledge rather than on physical resources or natural raw materials. Knowledge is well recognized as a valuable asset underlying the competitive advantage of firms (Reisman, 2005), which implicates that its transfer is a critical factor for improving productivity (Janis, 2003) and innovation (Reisman,

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2005). Studies on innovation of products and processes have shown the vital importance of external sources of knowledge (Amara, Landry & Traoré, 2008). Universities, community colleges, public research organizations, knowledge-intensive business service (KIBS) firms, professional associations, advisory bodies and knowledge workers are considered as intermediaries facilitating the transfer of knowledge supporting the innovation process in firms (Landry, Amara, Cloutier & Halilem, 2013).

Developing countries and emergent economies are constantly at risk of being marginalized and excluded from the benefits of the global knowledge economy, which could jeopardize the purpose of eradicating poverty and achieving sustainable development. One of the causes of this threatening marginalization is the absence of higher education systems to train enough and highly qualified human capital at Ph.D. level; fundamental for the increase of the knowledge pool from which the society as a whole can benefit in terms of the production of innovation (Casey, 2009). In this scenario, universities are crucial actors in ensuring economic development not only by training highly qualified human capital, but also by producing new knowledge with innovation potential. Scholars agree with the fact that the institutionalization of the university-industry relationships has led to more intensive and direct involvement of universities than it was seen before (Geuna & Muscio, 2009). These enhanced relationships have added some entrepreneurial objectives to universities which have been referred to as a third mission (Etzkowitz, 1998).

Changes in the way knowledge is produced and used by society have imposed strengthening the interactions between university and industry. This increasing environment of interactions has led to recognize the importance of training new Ph.D. students for this growing labor market. Training of Ph.D. students within the framework of university-industry relations has several benefits for economic growth based on generation and transfer of new knowledge. Within this context, we have used an analytical tool consisting of an international and comparative education methodology aimed at showing the increasing trend of involving Ph.D. students in the cooperative interactions between university and industry in developed countries, in contrast to what is happening in a developing country such as Colombia.

From our analysis, we have concluded that the demand for more qualified and specialized researchers in business/industry has led to new versions of Ph.D. programs, such as Industrial Ph.D. Programs (IPPs). On the other hand, we have found that the cooperation with industry to develop Ph.D. programs is relatively weak in Colombia, as well as the university-industry relationships in general, even in the context of the Latin American region. Despite this fact, we argue about the existence of a critical mass of university researchers and absorptive capacity in some specific industrial sectors that might make possible the operation of IPPs as long as policy makers recognize that knowledge transfer, embodied in researchers and Ph.D. students, is a central factor for building and maintaining a competitive national system of innovation.

In this paper, we argue for the alignment of the so-called third academic mission of economic development with the traditional academic missions of teaching and research (Etzkowitz, 2002; Etzkowitz & Leydesdorff, 2000), through the implementation IPPs as a mechanism for strengthening the innovation process of firms and countries' economic growth.

Research Questions and Methodology

Within this framework, the present work aims to answer two questions. First, have the IPPs improved economic performance and innovation in developed countries? Second, will the IPPs contribute to boosting economic growth in a developing country such as Colombia? To answer these questions, this work is adopting the international and comparative education methodology, which is basically addressed to describe a certain educative phenomenon presented in a set of countries. By addressing a particular phenomenon, researchers aim at deriving useful knowledge with the potential of transforming a specific system of education (Bray, 2014; Epstein, 1994). Currently, international organizations, such as the World Bank and the Organisation for Economic Co-operation and Development (OECD), are using this methodology to make recommendations to different countries interested in improving and strengthening their education system (Bray, 2007). By way of the example, over the last two decades, the World Bank and the OECD have been making several studies on some countries' higher education systems (OECD & WB, 2009, 2012). With the intention of contributing to improving these systems, the adoption of new training models is suggested. It is noteworthy to highlight that the suggestions derived from this kind of studies are based on the description and analysis of higher education systems at international level.

The literature used in this paper relies on primary institutional information from the Colombian institutions *Ministerio de Educación Nacional* (MEN), *Departamento Administrativo de Ciencia Tecnología e innovación* (Colciencias), and *Observatorio Colombiano de Ciencia y Tecnología* (OCYT). Working papers and some articles published in Spanish in national peer-reviewed journals were also used. Previous

national or international publications on the Colombian higher education system did not show a perspective on the feasibility of introducing IPPs in the Colombian higher education system. This paper thus tries to bridge this knowledge gaps by systematically supporting the development of this particular type of Ph.D. education. In searching relevant international literature, databases (ERIC, JSTOR, SpringerLink, and ScienceDirect) were accessed and specific keywords and thesaurus descriptors were used. We searched online for the institutional publications from the World Bank, the Organisation for Economic Co-operation and Development (OECD,) and the National Science Foundation (NSF) dealing with higher education and doctoral programs. This literature provided us with an international benchmarking for achievements of Colombian university-industry collaborations. Additionally, online access to primary institutional information about IPPs performance in different countries allowed to make comparisons between Colombian Ph.D. programs and those from developed countries.

Theoretical background

Increasing Earnings through a Ph.D. Degree

Higher education has always been a key way for upward social mobility as education and skills are important factors that increasingly determine outcomes in the job market by giving support to meritocracy. It is well documented that all university graduates enjoy a large earnings advantage over non-graduates, although significant wage variations have been observed between degree subjects (de Vries, 2014). Studies regarding the value of educational qualifications emphasize the premium these qualifications can confer to those individuals who hold undergraduate degrees, in comparison to those who do not. The significant differences in lifetime earnings between college and high school graduates have been specially highlighted (Conlon & Patrignani, 2011; Greenaway & Haynes, 2003; Universities UK, 2007). For UK, substantial earnings returns to Master's for men (8.95%) and women (10.3%) have been reported in comparison to those having an undergraduate degree. The premium achieved by those holding Ph.D. degrees is substantial and stands at approximately 16-17% (Conlon & Patrignani, 2011). However, previous studies have shown postgraduate premia compared to those of persons who having the basic qualifications for attending university decided not to enroll (O'Leary & Sloane, 2005). For instance, male holders of a Master's degree earned 29% more than the baseline, and women obtain 55% more. Holding Ph.D. degree brought further returns as men earned 31% and women 60% more than their equivalent comparators, although differences in Ph.D. returns were recognized depending heavily on the field of study.

In discussing these findings, Casey (2009) highlights that wages are reflecting marginal productivity, since Ph.D. degrees substantially enhance productivity of their holders, mainly in fields such as medicine, sciences, business and finance, and engineering. However, in the case of PhDs in Social Sciences, arts, languages and education, wages seem not to reflect marginal productivity. Considering that their activities are mostly performed in higher education, a sector much less open to market forces, they are supposed to be compensated by non-monetary benefits such as autonomy in their intellectual and academic labor (Casey, 2009). Large differences in first-job salary not only between graduates from different degree subjects, but also between graduates from different universities have been reported as graduates from elite universities enjoy starting salaries higher than those from less prestigious universities (de Vries, 2014).

Despite the steady increase in the number of Ph.D. degrees awarded across the OECD countries, a sustained labor market premium of doctorate holders has been witnessed with respect to other highly trained citizens (Auriol, Misu & Freeman, 2013). However, holders of Ph.D. degrees in Natural Sciences and Engineering (S&E) are more likely to be engaged in research activities, whereas those having Ph.D. degrees in Social Sciences find more opportunities in non-research jobs. Ph.D. holders in Medical and Health Sciences generally earn better wages, and also those in the business sector (de Vries, 2014). Earnings in Agricultural Sciences and Humanities have been found to be typically below the overall median in most OECD countries (Auriol *et al*., 2013).

In the case of the United States, workers with Science and Technology degrees also have higher earnings than those holding degrees in other fields (NSF, 2014). Earnings for S&E Ph.D. holders generally continue to increase through their careers, whereas this is not the case for those holding bachelor's and master's degrees in S&E. Regarding median salaries of S&E graduates, by degree level, there is evidence showing that Ph.D. holders earn 49.1% and master's holders 19.2% more than those holding a bachelor's degree (NSF, 2014). In contrast, non-S&E degree holders earn more than S&E degree holders, regarding professional degree holders.

It should be highlighted that career rewards for those highly skilled individuals in general, and Ph.D. holders in particular, often extend beyond salary and employment benefits. Ph.D. holders have personal rewards such as doing the kind of work they have trained for (NSF, 2014). In the case of the United States, those holding S&E degrees or working in S&E occupations are affected by lower rates of unemployment than the general labor force. For instance, during the period 2006-2010, unemployment rate among those who hold a doctorate ranged from 1.6% to 2.6%, whereas the same rate for the broader labor force ranged from 4.0% to 9.6% (NSF, 2014).

The Human Capital Theory (Becker, 1993) maintains that investments in education lead to higher market participation, productivity and earnings, whereas the Market Signaling Theory claims that employers recognize education credentials as a signal that an employee has the potential to perform high levels of productivity (Stiglitz, 1975). This means that people having knowledge and skills, but no educational credentials, cannot signal their productive potential to an employer. In other terms, the productive role in contrast to the symbolic role of PhDs is part of the debated between these alternative theories. Then, the earnings of PhDs could have a large component of signaling rather than reflecting the human capital accumulation in terms of knowledge, experience and skills (Luo, Koput & Powell, 2009). Moreover, human capital cannot be taken out of social relationships as returns to intelligence, knowledge and skills depend on individual social capital. The investment in human capital is not enough to generate social and economic progress if the location of individuals in the social structure of the market excludes them from formal channels of knowledge and opportunities (Russ, 2014).

As previously shown (Acosta & Celis, 2014), employment rates for those holding a Ph.D. degree are relatively higher than those observed for the general labor force in Colombia. Employment rates for new graduates from Ph.D., master's and short term specialization/medical residency programs were very similar (92.9, 93.0 and 92.9%, respectively), but higher than those for bachelor's degree holders (80.6%) (OLE, 2013). Based on OLE statistics (2013), the estimated monthly earnings of individuals having a Ph.D. degree are considerably higher than those of the other postgraduate degrees total workforce. The monthly weighted average salary for a new Ph.D. holder was $5,470,376 Colombian pesos (US$2,200 dollars) compared with $3,659,083;

$2,724,971; and $1,604,583 COP for master´s, short term specialization and bachelor's holders, respectively. According to these figures, it seems that in Colombian is more encouraging undertaking a Ph.D. degree in general than in the United States, since Ph.D. holders earn about 240.9% and 49.5% more than bachelor's and master's holders, respectively. Considering other salary factors and compensations, the average salary of a Ph.D. holder in Colombia reaches about US$34,000 dollars a year, which is significantly lower (about half) than that earned by a faculty member with the rank of instructor in an average university in the United States (The Chronicle of Higher Education, 2014). The picture is more dramatic and depressing if we look at the first job salary for a new Ph.D. holder in a public university: US$18,720 a year (MEN, 2014).

However, a different picture is obtained after comparing the social status conferred by having a Ph.D. degree when using the respective poverty thresholds (DANE, 2016; U.S. Department of Health & Human Services, 2015). The calculation in terms of first job salary shows that it is more rewarding working in Colombia than in United States because Ph.D. holders achieve income above 4.02 times the Colombian poverty threshold whereas those working in United States achieve income above 2.3 times their respective poverty threshold. However, it must be kept in mind that there are different methods for determining the poverty threshold, and that this usually differs between developed and developing countries. Nevertheless, in the general context of demand and supply considerations, it is well documented that a rise in the proportion of better-educated workers can benefit uneducated workers, while the wages of educated workers undergo a decrease that might be attenuated in some extent by eventual spillovers. Addressing the possible general equilibrium effects of increasing the proportion of Ph.D. holders should be a priority of policy makers. Further research should be conducted in order to estimate these potential effects.

It has been shown in the case of Chile and Colombia that the returns to higher education are quite heterogeneous depending on the higher education institution (HEI). The net economic returns to university degrees were found to be, on average, positive, whereas those from technical education approached to zero in both countries (González-Velosa, Rucci, Sarzosa & Urzúa, 2015). The high dispersion of the net private benefits to higher education in these countries implicate that a high proportions of graduates could be having negative returns. Then, higher education, in these cases, does not facilitate the social mobility but contributes to perpetuate the social stratification. In the case of Colombian Ph.D. education, there is not a systematic study on the net economic returns of graduating from a Ph.D. program, except that the Colombian higher education labor market is split into two sectors represented by public universities and elite private universities providing better wages and job security, in contrast to the so-called "garage" university sector that relays on faculty hired by semester and paid per lecture hour (Acosta & Celis, 2014). However, this sector usually has no graduated training and does not hire Ph.D. holders as faculty members. A legal framework that governs the salary of faculty working in Colombian public universities prevents from differences in the factors determining the salary. Faculty score points based not only on academic degrees, faculty rank, and seniority, but also on publication productivity (Acosta & Celis, 2014).

Ph.D. Production and Improving of Economic Performance

The consensus that higher education is a public good has been fading away during the last decades. Many countries have entered the mainstream thought that higher education is largely a private good and highly educated people is not offering public benefits to society or nation. The new dominant philosophy emphasizes that higher education is a private good that provides benefits only to the individual graduating from university but not to society as a whole. Accordingly, the individual, not the society, should pay the costs of higher education. For developing countries and their higher education systems the implementation of this philosophy is leading to a situation even worse, because these countries were unable to build a high quality education system during the time higher education was not considered a private good. Within this philosophical framework, having a Ph.D. degree enhances earnings which have been considered as an indicator of private returns from possessing an academic qualification (Casey, 2009). This means that the marginal return to a Ph.D. degree is just the wage, which is clearly higher than that of those lacking this qualification. Then, a convincing argumentation should be introduced to justify public support for Ph.D. training.

In some countries it has been emphasized that Ph.D. education should be considered as a public good. This consideration need to be explained convincingly in order to gain support from society paying taxes (MSTI, 2006). Within this point of view, Ph.D. education serves to society needs and must therefore be funded essentially by the state. Following Casey's rezoning (2009), one way of addressing this issue is by considering that a Ph.D. must enhance not only the productivity of the individual having this qualification, but also of the society as a whole. Economists usually argue that the private sector is not willing to invest in something that spills over to others who had not contributed to the investment. Why sponsoring privatively the production/training of PhDs could benefit other beyond the private sponsor? The production/training of a Ph.D. is inherently associated with the generation of basic knowledge, which is publicly available. Moreover, those who hold a Ph.D. degree not only enhance their own productivity but also that of those lacking a Ph.D. degree interacting with them (Casey, 2009).

From the point of view of Endogenous Growth Theory, the economic growth has been attributed to endogenous forces (Romer, 1994), conferring to investment in human capital, knowledge and innovation a pivotal role in economic growth. This theory highlights that education enhances growth, producing positive externalities and spillover effects that enable economic development. Thus, if education at Ph.D. level enhances growth and also benefits the society as a whole, it is quite reasonable to argue that the whole society must fund Ph.D. training through public investment. Although the contribution of endogenous growth models and neoclassical growth models to explain the economic performance remain controversial, Ph.D. holders who have accumulated considerable human capital through education have been recognized as one of the key factors supporting creation of knowledge-based economic growth (Auriol, Schaaper & Felix, 2012).

PhDs carry with them both codified and tacit knowledge, which is of great benefit in industry engaged in solving complex technological problems. Public investment in graduate training, particularly at Ph.D. level, has been considered to be a driving force of economic growth, even more so when it promotes enhancing the networks between the private business world and universities. This is the case of IPPs which are a key component of knowledge transfer between universities and industry contributing to advancing innovative R&D and enhancing the growth and competitiveness of industry (DCTI, 2007; Thune, 2010).

University and Innovation Systems

The traditional role of universities, which had remained focused on education and basic research/science, has now been overwhelmed by additional functions such as knowledge and technology transfer to industry, knowledge commercialization, and a more active role in regional and national innovation systems. Most developed countries have emphasized the economic impact of publicly funded research, meanly in the cases of high-technology and knowledge-based sectors where innovation processes require the more advanced scientific inputs (Bozeman, Rimes & Youtie, 2015). In this context, the university-industry relationships have been largely studied by academic experts who have highlighted knowledge and technology transfer as a crucial factor involved in promoting higher productivity, economic development and competitiveness (Bozeman *et al.*, 2015; Mueller, 2006).

The European Commission (EC) has stated: "Innovation is now the single most important engine of long-term competitiveness, growth and employment" (2001, p. 11). Although the understanding of the innovation process is currently changing, innovation has become the integral driver of the knowledge economy and a central component of improving the efficiency of production factors (Brécard *et al*., 2006). Early understanding of the science and technology and its relation with economic growth was centered in the so-called "linear model of innovation" stating that innovation starts with basic research, followed by applied research and development, and ending with production and diffusion (Bush, 1945; Godin, 2005). However, innovation process has no longer been understood as linear process of invention but rather as a systemic, networked phenomenon (Deakins & Freel, 2003; EC, 2001; Etzkowitz & Leydesdorff, 2001). Last decade's literature on technology transfer has underlined its non-linear nature. The transfer of university-generated knowledge into market successful innovation is a non-linear process and, in this context, some mechanisms and models have been analyzed (Bozeman *et al*., 2015; Bradley, Hayter, & Link, 2013). University contributions to the innovation process are not only limited to the technology transfer, they extend to the production of highly skilled human capital, the generation of basic knowledge and the generation of spin-out companies (Philpott *et al*., 2011). Moreover, maintaining and improving regional and national innovation processes require the successful convergence of the university, industry and state (Etzkowitz & Leydesdorff, 2000, 2001; Gibbson *et al*., 2006; Inzelt, 2004).

Since the enactment of Bayh-Dole act in 1980, universities have increasingly been key players in technology transfer. As universities have become more entrepreneurial, the identification of factors affecting technology transfer performance has become a central research topic. Mechanisms of technology transfer include relationships among university, industry and government, joint laboratories between academia and business, open innovations, spinoffs, university acquisition and distribution of intellectual property, research contracts, mobility of researchers, joint publications, and a flow of graduates to the industry (Bradley *et al*., 2013; Heinzl *et al*., 2013). Case findings suggest that the progression towards entrepreneurial university ideal is highly context-dependent and may not be suitable for all universities (Philpott *et al*., 2011). In addition, research emphasizes that top-down push towards the entrepreneurial university ideal may be detrimental to promote academic entrepreneurial activity; in contrast, a bottom-up approach is suggested as more conducive to fostering academic entrepreneurship (Philpott *et al*., 2011).

An important way of university involvement in economic development process is through collaboration with industry, exemplified by joint research projects addressing innovation. University–industry research collaborations (UICs) have been increasingly recognized as an innovation mode (Bianchi *et al*., 2011; van de Vrande *et al.*, 2009) in which firms and universities complement their skills in order to enhance research outcomes. However, the importance of knowledge as a valuable input conferring economic advantage has produced a change in the university expectations to incorporate commercialization of research outcomes alongside of traditional missions of teaching and basic research (Macho-Stadler, Pérez-Castrillo, & Veugelers, 2008). Some criticism has risen as universities are encouraged to become more entrepreneurial and change their culture, governance and management (Levidow, 2002; Rip, 2002). It has been traditionally considered that universities are driving by scientific goals far from profit or market approaches (Partha & David, 1994) and that their research results must be openly and freely communicated to the scientific community and society as a whole. These traditional considerations have been contrasted with the industry aims of protecting proprietary information as a mean of assuring financial return to investments. This cultural divide concerning academia and industry goals sometimes can result in tensions affecting the university-industry relationship's expectations (Bruneel, D'Este, & Salter, 2010; Burnside & Witkin, 2008). However, some authors think that university-industry relationships can ensure their success if both parties acknowledge their differences and work within them and cultivate trust (Hemmert, Bstieler, & Okamuro, 2014; Mora-Valentin, Montoro-Sanchez, & Guerras-Martin, 2004).

Reforms of Higher Education Systems

In response to the urgency of developing a pool of highly quailed human capital, many countries have reshaped and restructured their education systems. This human capital is seen as a key condition for knowledge production, technical innovation and economic growth (Kaur *et al*., 2010; Yaisawarng & Chu, 2014). Many developed countries and some middle income countries have also moved from an industrial-based economy to a knowledge-based economy (Kaur *et al*., 2010). Research and world-class universities play the role of developing highly trained knowledge workers to make possible the knowledge economy (Altbach & Knight, 2007; Kaur, Sirat, & Azman, 2008). However, reforms in higher education systems have two main actors: government and institutions themselves.

In the core of the debate about higher education reforms, particularly university reforms, and state-university relations is the university autonomy. However, the idea of autonomy that supports the political reforms of universities has undergone major shifts in many countries. The changing nature of the autonomy meaning has moved from one based on institutional trust and professional autonomy, to another based on organizational autonomy (Enders, de Boer, & Weyer, 2013). Over the last decades, the special status of the university as a social institution has been challenged as higher education reformers of many OECD countries have introduced measures aimed at changing the traditional status of universities (Olsen, 2009). The knowledge-based economy is demanding the aligning of universities with governmental policy goals of economic growth (Ferlie, Musselin, & Andresani, 2008). Regulation and funding policies are centered on accountability, performance indicators and the impact of university output on economic growth. Therefore, reforms are immersed in government-university relationships in which universities' decision making competencies include financial matters, management of human resources, students selection, academic programs and research facilities administration, among others; whereas government competencies include accountability requirements for monitoring university performance (quality assurance procedures, evaluation and accreditation agencies). Government goals related with having highly-trained human capital for complying with industry's interest should be compatible with the organizational autonomy of universities in order to be successfully met.

The authority and responsibility for reforms involving academic issues has been recognized to be residing in the university. Universities have expertise and information for academic decision making which are usually absent in government. However, new governmental control instruments have enforced the strengthening of universities as strategic organizational actors that must strengthen their managerial self-regulation and internal control capacities in order to improve their organizational performance (Enders *et al*., 2013). In other words, universities have become more autonomous but also more accountable, though more efficiency and effectiveness is expected from them. Despite the numerous reforms witnessed during the last decades in many countries, the curricular innovations have been more durable (Altbach, Gumport, & Berdahl, 2011). It appears to be that there is a worldwide consensus that university curriculum must ensure training for jobs of increasing complexity. Students are interested in receiving training that prepares them for the job market, while employers demand that the curriculum changes to meet the needs of the workplace. The increasing university-industry relationships are imposing that the knowledge and skills the firms need are incorporated into the curriculum (Altbach *et al*., 2011). Industries have established formal linkages with universities to perform joint research necessary to meet their interests. In other cases, some universities have signed contractual agreements with corporations to share research results. One of the most relevant examples of the university-industry relationships is the emergence of IPPs (DCTI, 2007; Thune, 2010).

Regarding the feasibility of introducing IPPs, universities that already have doctoral programs could use their autonomy to encourage candidates for pursuing PhD degrees and career paths associated with the business/industrial sector. However, from the point of view of the triple helix model (Etzkowitz & Leydesdorff, 2000), the university autonomy needs the decisive contribution of government and industrial sector for making possible the IPP initiative. Public funding and industry commitment to intensify production and innovation in knowledge are essential as well.

Nature of Industrial Postgraduate Programs (IPPs)

Since its origins in the late 19th century, doctoral training has been widely recognized as a research-teaching-study nexus (Clark, 1997, p. 242) by which students develop a series of skills to *discover, integrate*, and *apply knowledge* (Thurgood, Golladay & Hill, 2006, p. 3) in order to make original contributions to the advancement of disciplines. Doctoral training has additionally been regarded as a crucial educational level for the growth, reproduction and maintaining of national scientific communities (Lucio & Serrano, 1992; Schwartzman, 2007). In some countries, such as Germany, Ph.D. graduates have been instrumental in reproducing "the professions and elites in public administration, politics and the law, as well as in industry" (Enders, 2004, p. 422), whereas in the United States, Ph.D. training has played a major role in supporting innovation and economic growth and in helping this nation to become a global leader in science and engineering (NSB, 1998).

However, some changes have been suggested in order to make this training more functional for competitiveness. Kehm (2007) remarks two basic changes: The qualification of students for non-academic labor markets and the commodification of knowledge production. The former means that disciplinary-based education has to be complemented by the development of managerial and organizational skills while the latter implies that students must be able to commercialize knowledge. The same trend is found in doctoral education in some Nordic countries, such Sweden, Norway, and Denmark, where industry-based doctoral education is a new form of education that seeks to respond to the increasingly need of elevating the production of the industrial sector innovation (Salminen-Karlsson & Wallgren, 2008; Thune & Børing, 2014; Tiraboschi, 2014).

Historically, doctoral training has been devoted to educating students to follow an academic career (Enders, 2004). Although the enrollment in traditional Ph.D. has risen, the academic labor market has not grown in the same proportion (Cyranoski *et al*., 2011). In contrast, the demand for more specialized researchers in business/industry has increased and new versions of doctoral programs, such as industrial and professional PhDs, have emerged (DCTI, 2007; Edwards, 2009). These new forms of Ph.D. training programs are allowing their graduates to benefit from a widened and diversified spectrum of job opportunities in a number of non-academic fields. IPPs are well-established in countries such as Australia, Denmark, Finland, France, Japan, and the United Kingdom, and they have been considered the result of close university-industry partnerships (OECD, 2006). Unlike the traditional doctoral training, the IPPs are mainly addressed to equip students with industrial and business skills that enable them to transfer knowledge from academia to industry and produce and introduce innovation-intensive products in the global market (DCTI, 2007; Héraud & Lévy, 2005). IPPs allow the enterprise to gain an employee highly qualified who is also working on a project contributing to the enterprise's development, whereas universities gain expertise, experience and prestige associated with the education of the Ph.D. candidate including the associated scientific publications, communications and patents.

Referring to the British Engineering Doctorate Programme, Kerr and Ivey (2003, pp. 95-96) show how the IPPs are comprehensive doctoral training essentially characterized by "the development of innovative thinking while tackling real industrial problems, together with the continual broadening of [students' skills] through gaining and applying knowledge from taught elements" by making a research project, that aims to create and commercialize new products (Harman, 2002; Kerr & Ivey, 2003). Furthermore, students develop teamwork skills (Thune, 2009) and develop a capacity to better understand the industrial environment. This facilitates that students conduct research that should be suitable for the needs of industry, increasing the level of industry's production (Thune & Børing, 2014). As the traditional doctoral training (Acosta & Celis, 2014), the IPPs are a 4-year-full-time program (Kerr & Ivey, 2003). However, training for some Ph.D. students takes just three years. In countries such as France those who aspire to do the IPPs must be under 26 years and count on a master's degree (Héraud & Lévy, 2005).

To conduct the research project students have two supervisors (Salminen-Karlsson & Wallgren, 2008), one academic supervisor who is responsible for the acquisition of scientific skills, and an industrial supervisor who is devoted to the development of business skills. There are frequent meetings between supervisors in order to evaluate the progress of students' research projects. It is important to mention that both supervisors have a Ph.D. degree and experience in doing research in the context of industry-university collaboration. It means that supervisors are qualified to help students with their research projects, and more importantly, they know the two education environments –academia and industry– that are indispensable for the formation of students. Salminen-Karlsson and Wallgren (2008) additionally report that students consider their supervisors as supportive persons to the solution of students' personal problems. Commonly, it is not required that the university is national or foreign; however, a supervisor from a national university must supervise the studies completed at a foreign university (DCTI, 2007).

It is worth making clear that names other than IPPs have been used elsewhere to emphasize their industrial orientation. For instance, industrial Ph.D. training has been mentioned by the OECD (2006) to refer to different versions of industrial Ph.D. training in some countries, whereas the Norwegian Government has termed these programs as industrial Ph.D. Scheme. In some countries, such as Austria, government encourages and provides incentives to those already having a recent Ph.D. degree to transit from academia to industry (OECD, 2006). Yearly awards cover personnel costs for supporting scientists who wants to switch from a university to an Austrian company planning to expand its R&D activities. In the case of Netherlands, the Casimir Programme provides financial incentives for companies and knowledge institutions to undertake exchanges involving talented researchers from public and private sectors. The program is open to PhDs, Bachelor's-level research staff, post-doctoral researchers, university lecturers or senior lecturers, professors and researchers working in the private sector (OECD, 2006). A fellowships' scheme has been reported in the case of Canada where the Ph.D. applicants have two supervisors, one at the university and one at the company/enterprise (OECD, 2006). The Natural Sciences and Engineering Research Council of Canada (NSERC) manages two major programs, the Industrial Postgraduate Scholarship (IPS) and the Industrial Research and Development Fellowship (IRDF). The IPS program supports graduate students (M.Sc. and Ph.D.) to pursue their studies in collaboration with industry performing at least 20% of their research in the industry facilities. The IRDF program supports post-doctoral fellows to pursue their research in industry performing 100% of their research at company facilities (OECD, 2006).

The Knowledge Foundation's Company Graduate Schools in Sweden are aimed at allowing companies to increase the number of employees having advanced university degrees. This institution provides founding for doctoral students and also for development of industrial research schools. The program of theses company research schools includes among its goals to contribute to the university research development, increase knowledge within industry and reinforce collaboration between university and industry (Erawacht, 2012). The Swedish Government supports and strengthens the transfer of knowledge between academia and industry by promoting that researchers move more naturally between university and business and that Ph.D. students spend part of their training time working for a company.

France has a doctoral funding system comprising a national association for research and technology (ANRT) that represents public and private entities dedicated to research and innovation. The ANRT administers the French system of industrial agreements for training through research known as CIFRE. The Australian Post-doctoral Fellowship Industry (APDI) finances training costs for young researchers. This support represents the maximum contribution that may be paid as salary to the fellow from Commonwealth funds. The host institution must match local salary levels and the successful applicants are appointed by the institution for three years to be employed full-time on the approved project (OECD, 2006). The Danish Industrial Ph.D. initiative aims at enhancing R&D in the Danish business sector providing funds for Ph.D. fellowships for candidates wishing to work on a project defined by a company in co-operation with the university. The company is subsidized (50% of researchers' salary) and also the university for supervision costs and training and complementary business-targeted courses (OECD, 2006).

The Technology for Industry Fellowships (TIF) from New Zealand provides financial support for undergraduates, Master's and Ph.D. students and experienced researchers, to work on science, technology and engineering projects conducted in, and managed by, firms. Many companies felt positive about their role in helping students and exposing them to the commercial realities of business (OECD, 2006). The Enterprise PhDs program of the Foundation for Science (FCT) from Portugal aims to promote career diversification as well as collaboration between firms and universities. During the period 1997-2003, the FCT helped placing 77 Ph.D. holders and 63 Master's in nearly 50 firms, through the support of the Innovation Agency (OECD, 2006). The Becas FPI Programme (training of PhDs) from Spain has allowed Ph.D. students to develop short-term stays in enterprises for the first time in 2005. The Torres Quevedo Programme has provided financial support to about 1000 labor contracts for Ph.D. holders and technologists in enterprises and technological centers (OECD, 2006). These landscape shows that different approaches for industrial Ph.D. training are possible and that without a significant public financial support for these initiatives their future success is not guaranteed. Nevertheless, the present work will be focused only on IPPs defined in a strict sense as indicated above.

Feasibility of IPPs in Colombia

The Colombian Ph.D. training of human capital came too late to ensure a significant proportion of Ph.D. holders at present (Acosta & Celis, 2014). Despite the rapid increase of its Ph.D. graduates per million inhabitants over the last decade, Colombia continues to rank behind other Latin American countries. By 2013, this country graduated only 7 PhDs per million inhabitants and only 5.8% of higher education faculty members held a Ph.D. degree (MEN-SNIES, 2015). In the perspective of strengthening the university-industry relationships, the picture is not less worrisome. Recently, a study aimed at establishing some recommendations for building public policy to increase the number of Ph.D. holders in the Colombian industrial sector was conducted (Celis, Duque & Ramírez, 2012). After applying a methodology previously used for analyzing Ph.D. students' preferences for academia or industrial sector in the United States (Roach & Sauermann, 2010), a study showed among its results that 8 out of 10 engineering Ph.D. students surveyed and interviewed preferred working for academia rather than joining industry (Celis *et al.*, 2012).

Although the Colombian National Plan of Development (NPD) for the next four years (2014-2018) states that Science, Technology and Innovation (ST&I) are key strategies for assuring economic growth by driving the industrial productivity and improving the competiveness of economy, the financial component of the Plan is not clear (NPD, 2015). The budget of Colciencias, the main public agency financing ST&I, has remained about the same for over two decades without exceeding 0.22% of GDP (Asmar, 2015), while the total investment from public and private sources for research and development (R&D) never has surpassed 0.5% of GDP in the same period (Gómez & Mitchell, 2014). In contrast, other countries in the Latin American and Caribbean region, such as Brazil (1.2%), Chile (0.4%) and Mexico (0.45%), show higher investment in ST&I than Colombia (0.22%) (Gómez, 2015). Colombia's investment in ST&I is even well below that of the Latin American and Caribbean region (0.7%).

According to the source type of funding, the mean investment proportion in ST&I activities by public, private and international sector has remained in 58.38, 39.47 and 2.15%, respectively, during the 2003-2013 period, while the funding for R&D has been remained at 56.61, 40.05 and 3.34%, respectively, for the same period (OCYT, 2014). However, the current NPD assigns to the private sector the responsibility of providing 75% of the investment in ST&I activities during the 2014-2018 period (NPD, 2015). This assignment could be understood as a challenge or opportunity for technological improving and innovation as the proportion of non-innovative companies increased from 60.6% in 2010 to 73.6% in 2012 (OCYT, 2014) and the share of industrial activities in the GDP decreased from 24% in the 1970's and 20-22% in the 1980's to less than 12% nowadays (Clavijo, Vera & Fandiño, 2012). This fact is reflecting that the Colombian business sector is still largely comprised of low-knowledge intensive industries, which negatively affects its competiveness and exporting potential. In front of this background, enhancing the university-industry relationships constitute a valuable tool for linking the university knowledge generation with the industry potential for generating economic value-added. Industrial Ph.D. programs could be an ideal way for contributing to the knowledge intensification and innovation capacity of Colombian industry.

Understanding IPPs as a way of UICs, these programs are supposed to represent knowledge capital that contributes to the technological progress and innovation capacity of firms. Though the link between human capital (education) and economic growth is not straightforward and depends on many factors, it is well documented that investment in education not necessarily enhances economic growth, despite there are still strong reasons that it should (WB, 2007). In spite of being clear that the lack of qualified human capital is a limiting factor for economic growth, it is unclear that a more qualified human capital will increase economic growth. Empirical studies show conflicting findings about the relationship between human capital (education) and economic growth, and usually the hypothesis that human capital investment fosters economic growth is not supported. Cultural, economic, political, social and even local factors, as well as national and global determinants, can affect the impact of Ph.D. holders on economic growth. Nevertheless, education is one of the initial conditions that contribute to the long-term steady state toward higher levels of development (WB, 2007). Although IPPs are an important and necessary condition for strengthening the Colombian economic growth, they are not sufficient condition to ensure it.

The implementation of IPPs requires building strong collaborative relationships between university and industry, bringing together researchers from academic community and research departments from companies, and increasing significantly the public and private financial resources for conducting collaborative research projects. These strategies assume that scholarly community generating advanced knowledge in universities and Ph.D. holders involved in R&D applied in industry must be strengthened. Only 5.8% of faculty members working in the Colombian higher education system hold a Ph.D. degree, whereas about 0.03% of employees in industry hold this advanced degree (Acosta & Celis, 2014; MEN-SNIES, 2015). This suggests that, on average, the absorptive capacity of both university and industry is very low. This also means that the acquisition, assimilation, transformation and exploitation of knowledge might be undermined by the lack of sufficient Ph.D. holders.

The before mentioned shortage of PhDs is a major concern not only in Colombia but in many developing countries. In comparative terms, Brazil annually graduates 71 PhDs per million inhabitants, Mexico graduates 44, Chile 31, and Colombia only 7, whereas the Latin American and Caribbean region, on average, 38 PhDs (Lucio *et al.*, 2014; RICYT, 2015). The evolution of Ph.D. training in Colombia and its Ph.D. shortage have been recently described (Acosta & Celis, 2014; Gómez, 2015). To address this shortage of PhDs, three different goals have been proposed to reduce it (Gómez, 2015). These goals are set to reach by 2025 the average Ph.D. training rate of the Latin American and Caribbean region or the Brazilian rate or, alternatively, to continue with the Colombian current rate of training. Meeting these goals would lead to produce annually 60, 105 and 16 PhDs per million inhabitants by 2025, respectively. The costs for the starting point in 2016 would amount to $187, $250 and $93.7 US million dollars (2015 current currency) for meeting the goals of training 9.8, 10.3 and 8.7 PhDs per million inhabitants, respectively. The two most ambitious goals are, of course, far beyond the historical investment budget of Colciencias.

However, 41.8% of faculty members belonging to the National University of Colombia, the most representative Colombian public university, have a Ph.D. degree (Acosta & Celis, 2014). The Universidad de Antioquia, another public university, and the Universidad de los Andes, an elite-private university, maintain a faculty that is comprised of 38% (El Espectador, 2015) and 65% PhD-holders (UNIANDES, 2014), respectively. Regarding their scientific productivity, it may be assumed that the academic community of at least these universities has enough reputation to facilitate UICs. In fact, these universities, besides others, already participate in some UICs. For instance, the Ph.D. program in Agricultural Sciences at the National University of Colombia in Bogotá, has already awarded 40 Ph.D. degrees during the period 2006–2015. From this total number of Ph.D. graduates, 55% (22) carried out their thesis research work in collaboration with external institutions. Most of these PhD graduates (18) carried out their thesis in collaborative works with private industrial institutions, while the remaining 4 Ph.D. graduates conducted their research work in cooperation with other universities. Particularly, 10 Ph.D. graduates performed their thesis in collaborative works involving private agricultural federations of producers, some of which have well-established specific agricultural research centers.

Assuming that some public and private universities already offer formal Ph.D. programs in Science and Engineering and also maintain some relationships with industry, it sounds plausible to propose that, drawing from this critical mass in academia, the model of IPPs can be implemented. On the other hand, the presence of PhDs working in R&D in industry must be considered, although their presence is variable from one sector to another. In the case of Colombia, the agricultural private sector may be the more advanced industrial sector in the sense that some of the federations of producers have well-established research centers with human capital trained at Ph.D. level. Among these centers can be highlighted the National Center of Coffee Research (Cenicafe),[2] Research Center of Colombian Sugar Cane (Cenicaña),[3] Corporation Research Center in Oil Palm (Cenipalma),[4] and Research Center of Banana (Cenibanano).[5] However, it should be recognized that engagement of PhDs in a significant number of industrial sectors need changes in the prevailing culture and reassessment of the institutional insight supporting the traditional model of innovation. Industry should be persuaded to understand that modern industrial innovation involves the generation of innovative knowledge by flexibly combining disciplines and expertise since the networked nature of knowledge needs the establishment of new institutional frameworks where the UICs play a central role.

Public policy initiatives promoting triple helix-like interactions (Etzkowitz & Leydesdorff, 2000) are relatively recent in Colombia (Ramírez-Salazar & García-Valderrama, 2010). Some provincial University-Company-State Committees were created by 2007-2008 for promoting interactions

2 http://www.cenicafe.org/es/index.php/quienes_somos/nuestra_gente.

3 http://www.cenicana.org/web2/index.php/ares-de-innovacion.

4 http://www.cenipalma.org/menu-de-investigacion-e-innovacion.

5 http://www.cenired.org.co/index.php/centros-de-investigacion/cenibanano.

between these actors. An earlier committee of this kind had been initiated in 2003 with the leadership of the Universidad de Antioquia (Velázquez, 2009). Through this committee's initiative, the Corporation Tecnnova was created for promoting interactions between research university groups and industry, as well as strengthening trust and collaboration between companies, universities and the State. Despite these initiatives, the UICs in Colombia continue to be even weaker than in countries of the Latin American region, such as Brazil, where the UICs have been judged as being still incipient and weak, and concentrated in few industries (Steingraber & Gonçalves, 2010). Some Colombian innovative companies have created research groups and facilities, and administrative positions such as innovation manager for identifying key innovation problems and seeking solutions through collaborative research projects with universities (Cárdenas, 2007).

The increase in the number of academic Ph.D. programs has been paralleled by the number of publications and research groups formally classified by Colciencias. Despite the rapid increase in Ph.D. programs and graduates, Colombia hardly reaches 16 PhDs per 100,000 inhabitants, whereas Brazil reaches 44.8 and Chile 28.1 (Acosta & Celis, 2014; WB, 2012). This is a factor explaining why Colombia lags behind other Latin American countries in terms of scientific output. For instance, Colombia ranks fifth behind Argentina, Brazil, Chile and Mexico in the generation of academic documents (SCimago, 2014). This Ph.D. shortage also explains to a considerable extent why Colombian universities are absent in the world's top 500 universities that include 10 universities from Latin American countries (SRC, 2016). Taking into account that more than 90% of Ph.D. holders resident in Colombia are working in universities (Acosta & Celis, 2014; Gómez, 2015), it is expected that increasing their number, once the appropriate conditions for research are met, at least the scientific output and world ranking of universities will improve. In addition, having more Ph.D. holders increase the potential of knowledge transfer from university to industry.

Similarly, it should be highlighted that the generation of patents and prototypes has been negligible in comparison with that of publications (Cárdenas, 2007; SCimago, 2014; SIC, 2015). The low number of patents generated by universities is a proxy of the low stock of knowledge potentially applicable for industrial innovation. By 2014, only 62 patent applications were submitted by Colombian universities to the Superintendencia de Industria y Comercio (SIC) (Equivalent to a Patent Office) and 12 were granted (SIC, 2015). Despite the creative innovation of companies is not simply represented by the relative magnitude of R&D spending and the number of registered patents, as the profitability of corporate R&D spending and the quality of patent stock are more important (Obayashia & Yamada, 2008), the number of Colombian companies' patent applications reached 134 and only 57 were granted by 2014 (González, 2014). By comparing and contrasting patent activity statistics of some countries, it can be readily concluded that Colombia exhibits a relatively poor patent activity even in the Latin American region. Colombian patent activity in terms of patent applications by residents during the period 2010–2014 only reached 251 applications in comparison to 340 (Chile), 643 (Argentina), 1,210 (Mexico), 4,959 (Brazil), 14,972 (United Kingdom), 271,731 (Japan) and 287,831 (United States) (WB, 2015).

This relatively low patent activity of Colombia might be explained by either or both the limited R&D spending and high qualified human capital. It was recently found that too few Colombian companies are certainly innovative (OCYT, 2014) and it has been advised that the Colombian industrial sector must break down the barriers that prevent them from undertaking innovation initiatives in collaboration with universities (Cárdenas, 2007). In the case of Colombia, the university-industry collaboration for formal Ph.D. training is scarce and may be incidental, as indicated above. In this context, it is perfectly understandable the remark made by the OECD, which asserts that the Ph.D. programs are not connected with industry (OECD, 2014). Increasing human capital qualified at Ph.D. level in both university and industry is a key factor for creating initial favorable conditions needed for fostering innovation capacity of industrial sector. This critical mass is also crucial for making possible the implementation of IPPs, which in turn are central for building and maintaining the innovation capacity of companies.

Concluding remarks

This article provides argumentative support for the introduction of IPPs as a way of strengthening the collaboration between universities and industry in terms of being a crucial factor for boosting the innovative capacity of firms. Relying on the studies cited and on the Colombian primary institutional information, we emphasize on the feasibility of building this type of Ph.D. studies in a developing country such as Colombia, where its collaborative research networks between universities and industry are weak compared with those of the developed countries.

Colombian economy continues heavily based on the export of natural raw materials without added value, which threatens to exclude it from the benefits of a global knowledge-based economy. We point out that missing highly qualified human capital is one of the causes that jeopardize the purpose of eradicating poverty and achieving sustainable development in developing countries. In this context, Ph.D. holders are presented as critical actors for ensuring economic development through the production of new knowledge with innovative potential useful for firms, and for making possible the institutionalization of productive university-industry relationships.

Doctoral degrees, in general, and IPPs, in particular, have been highlighted in terms of their private benefits since graduates enjoy a significant earnings advantage in comparison to those lacking Ph.D. degree. However, the present article calls for public financing of Ph.D. training, mainly in developing countries, as focusing on the private benefit of graduates would lead to worsen the situation of developing countries, which were unable to build a strong higher education system and produce a significant high quality human capital trained at Ph.D. level in times when the public benefits of higher education were emphasized. Most developed countries share the policy that Ph.D. degrees are a public good by considering that PhDs contribute to enhancing not only the individual productivity, but also the productivity of the society as a whole, through a number of public externalities. Nonetheless, public investment in Ph.D. education cannot be thought in terms of a linear model of innovation linking university basic and applied research with the market. On the contrary, technology transfer is a complex and non-linear process implicating the successful convergence of government, university and industry. PhDs having research training in industrial environment are more likely to generate knowledge in collaborative works involving public and private research laboratories, and Government agencies responsible of supporting national innovation systems.

Although Colciencias have implemented some programs aimed at promoting innovation through financial incentives for research and development (R&D), and collaborative work between firms, universities and other research organizations (Crespi, Maffioli & Melendez, 2011), programs focused on promoting Ph.D. research in industrial environments have been absent. The establishment and public support of IPPs is not only important in diversifying career prospects for Ph.D. holders, but also in boosting research and innovation of firms. In times of knowledge-based economy, university-industry partnerships have become an important device for maintaining the innovative potential of many developed countries (Etzkowitz, 2008). Statistics on the distribution of Ph.D. holders according to the employment sectors show that on average over 35% of them work for the business/industry sector in many developed countries (Auriol *et al*., 2013). In particular, 47.2% of the Ph.D. holders in the field of science and technology are working in the business/industry sector in United States (Acosta & Celis, 2014). Introduction of IPPs may be an effective mechanism for fostering university-industry relationships in developing countries including Colombia. Public investment in IPPs have proven to be beneficial for university and firms as knowledge transfer is bidirectional, the firms develop highly qualified human capital and universities have the opportunity to form Ph.D. candidates trained in research subjects available in the private sector.

Despite the absence of Ph.D. programs formally defined as IPPs, it deserves to be mention that some Colombian public and private universities offer Ph.D. programs in Science and Engineering and in addition maintain some relationships with industry. We propose that universities and industry can draw from this critical mass in academia to implement the model of IPPs. However, the presence of PhDs working in R&D in industry must be considered. The proportion of PhDs working in R&D in the Colombian industry is certainly small (Acosta & Celis, 2014). Nonetheless, it is encouraging that the agricultural private sector has well-established research centers with Ph.D. holders systematically involved in research in some industrial crops. Disappointingly, this is not the case for most of industrial sectors. Colombian industry is very prone to employ staff for primary functions, and mainly for management and maintaining of some technology imported from developed countries, rather than creating new technological alternatives and innovation. It should be recognized that engagement of Ph.D. holders in many industrial sectors is not an easy task. Changes in the prevailing culture that keeps industry away from knowledge intensification of production are urgently needed. Industry should be persuaded to understand that modern industrial innovation encompasses the generation of innovative knowledge derived from the confluence of disciplines and expertise given the networked nature of knowledge where the UICs play a central role.

Although innovation has become a central issue of policy-making in many developing countries in connection with achieving a number of social and economic goals, public policy initiatives promoting triple helix-like interactions are relatively recent in Colombia. Although the growing number of Ph.D. programs has been paralleled by the number of publications and research groups, it should be mentioned that the generation of patents and prototypes by Colombian universities has been negligible in comparison with that of publications. This too low number of patents is an indicator of the low stock of knowledge potentially applicable for industrial innovation. The asymmetric competition represented by the Free Trade Agreements (FTA) could be explained at least in part by the lack of generating qualitative improvements in many products and processes. Innovation has been highlighted as a decisive factor for building and maintaining economic and commercial competitiveness of nations, but this is not possible without highly qualified human capital. IPPs can not only ensure a more effective transfer of knowledge between university and firms, but also contribute to the advancement of innovative R&D that gives support to economic growth and competiveness of firms and countries as a whole.

Taken together, the previous analysis shows that it is quite feasible to draw from the critical mass of PhDs working in several public and elite private universities and in some industry sectors to implementing IPPs. The implementation of IPPs is appropriate, desirable and feasible, not only in terms of strengthening or introducing a way of UICs, but in anticipating recognizable economic, institutional and social benefits for both parties. These benefits might include, for the university, source of revenue, patents, contribution to local or national economic development, exposure of students and faculty to practical problems and ideas, access to equipment and facilities, publication of scientific papers, and service to the society, and, for the industry, new products/processes/services, improved competitiveness, wealth creation, access to knowledge and technology, incorporation to networks and enhanced reputation, among others. The previous analyses allow concluding that it is certainly obvious that transfer of knowledge and technology is a critical factor for enhancing productivity and innovation of developed countries, which have a well-established research platform based on research universities and other institutions, which interact successfully with a significant absorptive capacity exhibited by industry. It is not less true that implementing IPPs in Colombia is an opportunity to set up one of the critical initial conditions that will contribute to a long-term steady state toward higher levels of growth and development of the Colombian economy. We certainly hold the view that maintaining universities divorced from national economic development has only contributed to deepening the technological, economic and political dependence.

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