EXPLORING AND PROPOSING A POSITIVE CHANGE ON ENGINEERING EDUCATION AND R&D STRATEGIC ALIGNMENT TO FOSTER THE ECONOMIC GROWTH IN COLOMBIA

By

DUARTE GARCIA, Jose andres

THESIS

Submitted to
KDI School of Public Policy and Management
in partial fulfillment of the requirements
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MASTER OF DEVELOPMENT POLICY

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Committee in charge:

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ABSTRACT

EXPLORING AND PROPOSING A POSITIVE CHANGE ON ENGINEERING EDUCATION AND R&D STRATEGIC ALIGNMENT TO FOSTER THE ECONOMIC GROWTH IN COLOMBIA

By
Jose Andres DUARTE GARCIA

Some empirical studies suggest a relationship between economic growth and the number of engineers. In Colombia, the number of engineers has been part of discussions but through this work we suggest that the debate should be moved and focused on the quality of engineers since the quantity seems to be moving according the demand despite some arguments stressing the contrary. The quantity of engineers is important –and we will prove that the situation is not critical as has been stated during many years comparatively with other fields of knowledge- however it is more important for the current stage of development of Colombia to call the attention towards a fundamental aspect of the engineers being supplied: the quality and harmonization of them upon the economic growth. As will be explained in this work improving the quality of engineers is key to make the next generation of engineers more competitive and more aligned with the innovation and research needed in Colombia to bring better economic performance. Already the country aims the growth of some sectors that require a quality improvement on engineers able to apply reverse engineering and also do R&D which suffers from small number of researches, patents, projects aligned between public investment in R&D and market needs. Based on the endogenous growth theories, the number of engineers and good quality of them could develop R&D

to improve the level of productivity and output understood as gross domestic product, GDP which is attached to the concept of economic growth and development. In this work we will go over the most relevant data and information referring to these issues and we will come with policy directions accepting that at this stage for Colombia the quality is more important than quantity and therefore government interventions with the support of the private sector and the academia is vital for boosting the economic development and future growth of Colombia. The Korean case of KAIST will be brought into consideration as a different alternative to push for the quality of engineers and more R&D to achieve better economic growth.

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ABBREVIATIONS AND ACRONYMS

DANE	National Administrative Department of Statistics Departamento Adminsitrativo Nacional de Estadística
DNP	National Planning Department Departamento Nacional de Planeación
FTA	Free Trade Agreements Tratados de Libre Comercio
GDP	Gross Domestic Product Producto Interno Bruto
GRI	Government Research Institutes Institutos de Investigación Gubernamental
IDB	Inter American Development Bank Banco Interamericano de Desarrollo
ILO	International Labor Oganization Organización Internacional del Trabajo
IT	Information Technologies Tecnologías de la Información
MEN	Ministry of National Education Ministerio de Educación Nacional
PND	National Development Plan Plan Nacional de Desarrollo
PTP	Productive Transformation Program Programa de Transformacion Productiva
UNESCO	United Nations Educational, Scientific and Cultural Organization Organización de las Naciones Unidas para la Educación, Ciencia y la Cultura
R&D	Research and Development Investigación y Desarrollo
WB	World Bank Banco Mundial

1. INTRODUCTION

Some studies suggest a strong relationship between economic growth and the number of engineers (Maloney & Valencia; 2014). Other studies compare the numbers of lawyers and engineers in different countries (Murphy et. al; 1991) finding that the ones with more engineers tend to grow faster. In general, it has been proven and assumed that engineers play a key role on the industry development and economic growth[1].

In the last years, it has been common to find in articles, newspapers, and academic debates, etc. that Colombia is lacking of enough engineers matching the demand in the market side. It has been also common to hear about the inadequate composition of enrolled and graduate students from tertiary education level where the majority of the future workers are choosing rent seeking[2] professions such as law instead of going for engineering that could boost the economic development of the country.

Recent studies have also suggested the lack of specific engineers –or so called innovative engineers- such as information technologies engineers. In addition, the main national government

[1] By saying so, this does not mean that other fields such as social sciences do not play important roles. For example they help engineers to understand the problems in multidisciplinary perspectives which end up reflecting a more comprehensive way to solve public problems interfering with economic growth.

[2] The term rent seeking in this thesis will be used aligned with the characterization of it suggested by Murphy and others (Murphy et al.; 1991) where professions such as lawyers are seen as professions going to the mark for seeking rent instead of creating jobs, innovation and boosting the economy. In this characterization Murphy and others place aside the role of firms generating jobs.

policy directions to foster the economic development such as the Locomotives and the Productive Transformation Program, PTP, could be seen also as policies enlarging the demand of specific engineers and also claiming for increases in the quality of education needed for such professionals.

Nonetheless, how is actually moving the demand and supply of engineers by only into the tertiary education institutions enrolments and graduates from engineering in the last years? Are those well-founded discussions regarding the composition of students by fields in tertiary education institutions? How important is the problem of quantity of engineers and what are differences among other fields of professions that are assumed to have bigger numbers than engineering? Is it more important the quality considering the real size of engineers in Colombia and the market signs? All such questions and more will be addressed as also will be shown in a regression model proving what is the relationship between the percentages of engineers based on the total graduates for the rate of the economic growth in Colombia from 2001 until 2013.

The new economic challenges and characterization of modern economies that reached development and those catching up highlight the importance of matching the supply of engineering with the market needs locally and globally oriented for a good economic performance.

The quality is fundamental for the good performance and therefore we will review the most relevant reports from OECD, WB, and other institutions that bring notions on how far is Colombia from quality measured by the innovation size, R&D outcomes such as patents, among other factors directly tighted with engineering fields at early stages of development.

R&D is a key determinant for development, and it can be absorbed from outside –exogenously- or produced and absorbed from inside –endogenously- and that is how countries can catch up the first movers and more advanced, otherwise the paths from developed and developing nations will remain distant and would keep diverging. Colombia should join that track and make efforts to align the engineers and R&D projects to foster the economic development. R&D is highly related to technology, and technology is seen as the main source of productivity. The key determinants of the technological potential of countries are R&D, and qualified human work force that is related with the main suggestion of this work in terms of quantity and quality of engineers.

Understanding the linkage between good quality of engineers and R&D for growth and development is key. The countries are exposed more and more to international markets, and therefore too to international spill overs of advancements and technologies. The countries should understand these and bring positive changes with more expenditure on the quality of engineers and R&D as % of GDP.

The Republic of Korea is a very good example for developing countries regarding to its education policies in particular to those that helped the economy to benefit from a good quality supply of engineers able to link their academic knowledge with market oriented projects of national interest and global oriented needs. The case of KAIST – Korean Advance Institute for Science and Technology- is a very interesting case to study and refer as a good alternative that encompasses a different approach to work at tertiary education level to push up for better quality of its graduates and also deploy R&D with strategic goals.

Lastly, some conclusion will be suggested to make further analysis in benefit of the education policies to be drawn at tertiary level to increase its quality, stimulate more R&D and foster the economic growth.

1.1 Statement Of The Problem

By using a method from the policy analysis called problem sensing to identify the problem, we now make a list to illustrate the sensation that policy makers and public opinion have regarding to the supply and demand of engineers, including only statements, articles, and interviews done to policy makers, stakeholders, academy representative regarding to this issue in the last 7 years:

Table 1: Problem sensing: source and main points about engineering in Colombia

Source	Main points
The most influential magazine called *Semana* in September of 2014 wrote and editorial with some interviews to Javier Chaparro, Dean of Electronic Engineering of the School of Engineering,	The article asks Where are the engineers? Talks about how people choose other careers instead of engineering and the shortage in some areas now and the one expected in 4 years for some sectors.

and also quotes the Ministry of IT[3].	
Brecha de Talento Digital is an study done by the EAFIT University and a consulting group hired by the Ministry of IT in 2014.[4]	The creation of more engineers in particular of systems and IT are fundamental to the sector for keep growing. The government should extend its scholarships and loans to technical/technological and professional education on engineering.
Andres Oppenhaimer influential journalist in its book *Basta de Historias.*[5]	Broadly speaking he says that Latin America is having producers looking for good engineers that sometimes are not even provided by the universities.
The most read economic newspaper called *Portafolio* in February of 2008 written by Juan Guillermo Londoño quotes statistics from the Colombian Association of Engineering Faculties (ACOFI), Gonzalo Ulloa the Dean of Engineering from the ICESI University, and the president of Ecopetrol – the biggest national oil company- Javier Gutierrez.[6]	The article claims that there is a lack of engineers to push up the productive sector.
The second most read newspaper called *El Espectador* made an article on Jul 2014 based on an interview to the Minister of IT.[7]	There is a shortage of 15.000 thousand engineers today in IT fields, and based on current plans to expand the digitalization of the country, by 2019, there will be a shortage of 90.0000 engineers. The high schools are not informing properly potential students on engineering. The names of programs on engineering are confusing when the names are close.
One of the most important Universities in the country called Javeriana made an article on March 2014 quoting the Dean of School of Engineers in Antioquia and Carlos Alberto Palacio the Dean of Engineering	The situation of engineers in Colombia indicates that there is a trend of decreasing interest on studying engineering that is also seen globally, but only proved in some universities. In general since 2005 to 2012 the number of enrolled students has been increasing. And also claims that engineers are not fitting the demand and market needs plus low integration with

[3] Magazine Semana. *Where are the engineers?* Nov 2014. Retrieved from http://www.semana.com/tecnologia/articulo/y-donde-estan-los-ingenieros/402945-3

[4] Infosys –Universidad EAFIT *Brecha de Talento Digital*. 2014.

[5] OPPENHAIMER Andres. Basta de historias; 2010.

[6] Portafolio Newspaper. *Hacen falta ingenieros para impulsar al sector productivo.* Feb; 2008. Retrieved from http://www.portafolio.co/archivo/documento/MAM-2824363

[7] El Espectador Newspaper. *Hay deficit de 15.000 ingenieros para la industria TIC: MinTic*. Jul; 2014. Retrieved from http://www.elespectador.com/noticias/economia/hay-deficit-de-15000-ingenieros-industria-tic-mintic-articulo-503625

Faculty from Antioquia University, and also Marta Lucia Villegas, President of ICETEX –the institution in charge of providing loan to guarantee access to tertiary education. In addition, an study from Edgar Serna from Remington University Corporation, and Alexei Serna from Research Institute of Antioquia[8]	innovation and technology, which make the Colombian engineer, be situated far from the contemporary world. On the other hand, from other study, it was found and excessive number of programs in engineering being offered based in UNESCO comparison in 2010. In fact from the study is found that Colombia has two times more number of programs in engineering than Brazil and Mexico countries that triple Colombia in population and double in size of economy.
Interview to the Minister of IT done by the newspaper *El Pais*[9], on May of 2015	We need more engineers than lawyers.
Book written by Andres Openhaimer in 2014[10].	Based in the *Red de Indicadores de Ciencia y Tecnologia (RICYT),* iberoamerican and intramerican, 63% of the 2 million of young people that graduates yearly in Latin-American and Caribbean obtain their graduation in social sciences and humanities, while only 18% of graduates are for studying engineering, exact sciences and natural sciences, the rest graduates from medicine, agriculture and other fields.

By using another public policy analysis method, such as the boundary analysis, we could identify and delimit the problem perceived as follow in the next model[11].

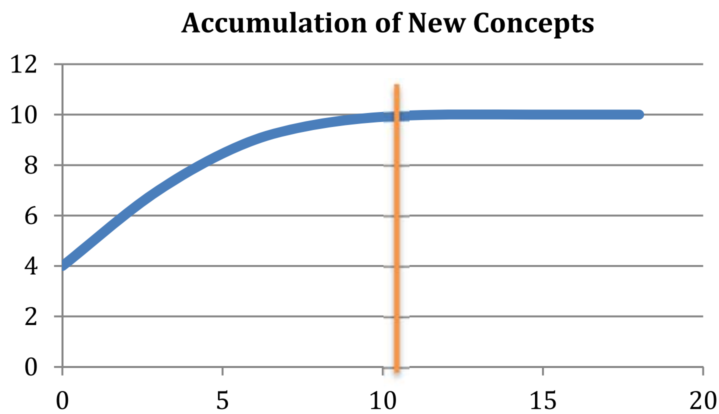
[8] Javeriana University website. *Situacion de la ingenieria en Colombia.* March 2014. Retrieved from http://www.javeriana.edu.co/javerianaestereo/portal_919/?p=11108#.VX5w1UuRk4M

[9] Diario El Pais. *Necesitamos mas ingenieros que abogados.* May 2015. Retrieved from http://www.elpais.com.co/elpais/economia/noticias/necesitamos-ingenieros-abogados-diego-molano-ministro-tic

[10] OPPENHEIMER Andres. *Crear o morir;* 2014.

[11] ORDOÑEZ, Gonzalo, DUARTE, Jose. Et al. Manual de Analisis de Politicas Publicas. UEC. Bogota 2013.

Figure 1: Boundary Analysis



Source: Adaption from Ordoñez, Duarte, Et al; 2013.

Where:
X axis = No of Experts and
Y axis = the Accumulation of New Concepts.
The orange vertical line represents the Border of the boundary analysis

The boundary analysis refers to the collection of new concepts and information from the problem, based on actors and expert's knowledge. The "*Analisis de Frontera*" or Boundary Analysis, means the point where additional numbers of experts or actor´s knowledge is costly and do not represent more knowledge gained because at that point the curve of accumulation of knowledge has an horizontal slope and therefore a constant or no marginal benefit from getting more experts knowledge until the problem is defined properly to continue with the analysis. In this particular case, a number of experts such as deans, scholars, ministers, public officials, influential leaders amounted that point where a definition of the problem is needed.

Regarding to definition of the problem for this work, or also called definition of the formal problem is stated as follows:

The lack of engineers in Colombia affects the economic growth rate, however considering the behavior of the supply of engineering in the country -comparatively speaking with other sectors of knowledge- the quality of the engineers and how the R&D could be strengthen to boost the economic growth.

1.2 Research Questions

Is Colombia lacking of engineers? In general is believed that Colombia has more lawyers and doctors than engineers. Complains and policies are suggested in order to increase the participation of engineers in the total number of enrolled students of other fields and also in comparison with the total number of graduates of other fields.

It is known how difficult it is to find the supply and demand of engineers and any other education field. To find them a number of variables –expected returns, tuition fees for engineering programs at public and private universities, tuition fees for other programs in other fields that could be considered as substitutes, income of household of the students, cost of provision of classes, indirect costs of studying such as housing if the potential student has to move from his current city-home, transportation costs, job market opportunities after 5 years of completing studies which could be very different to the conditions when the decision was taken, etc.- will have to considered. Also, all the assumptions will have to consider the education as a special market where the intervention of the government is needed not only to correct the market failures but also to guarantee that the education can be accessed to generate spillovers and different types of positive externalities for society.

However, it is possible to find the trend of demand of engineering –understood only as enrolled students- and supply of engineering – understood only as graduate students-. What is the trend of demand and supply of engineers from all tertiary education institutions and how the numbers, percentages, stand in comparison with other fields or other professions or even other countries.

More importantly, is it quantity just enough to bring economic growth in the current times? Why to focus on the quality of engineering?

And finally, what could be suggested to foster the economic growth and the quality of engineering in Colombia? What policies have been implemented in other countries to increase the quality of engineers and connect it with R&D goals?

1.3 Research Method

The research methods used in this work are composed on two kinds: quantitave and qualitative. Quantitave methods such as regression models are applied to find the relationship of engineering and economic growth in Colombia for the period 2001-2013.

In other words, a causal research is driven in order to identify causes and effect relationship (Zikmund et. al; 2012) of the changes in the percentages of engineers. The approach will be based on secondary data analysis, from the data banks made by the World Bank and Colombian Ministry of Education, MEN.

Qualitative methods such as literature review will be used to bring the foundations of the assumptions and logics follow throughout this work. Previous studies based on regressions will be considered and also reports and rankings done by international organization will be also part of the framing of the problem and the argumentation to work in these topics of economic growth, engineering, quality of engineering and innovation.

Public policy analysis methods (Ordoñez et. al; 2013) will be also used not only in the statement of the problem as could be observed above, but some other methods such as stakeholder analysis and evaluation of possible alternatives of solutions to the problem will be part of this work.

2. LITERATURE REVIEW

There is vast literature on the relationship between human development policies and economic growth. Human development is seen not only as a final result in the sense that it measures basic human well being but it is understood also as a critical input for the economic growth (Suri, et al.; 2011). In this study, we understand the policies on human development like an input and key determinant to obtain better economic growth[12]. We also focus particularly in tertiary education level and the impacts of engineering on economic development despite of the fact that less

[12] Other approaches consider human capital components such as education or health as outputs of the economic growth and increase in level of income.

literature can be found regarding to this topics.

Any achievement on tertiary educational means in the long run, less public expenditure on social welfare programs and more revenues earned through taxes paid once individuals enter the labor market or have created their business (OECD: Education at glance; 2014) but at the same time represents a fundamental determinant of what compose the productivity of each country and therefore its productivity.

Productivity might be understood in its basic definition as the total produced or output thanks to labor and capital or inputs, both affected positively by technology (OECD Manual: Measuring productivity; 2001). For other, productivity is seen as the ability to transform inputs in outputs (Isaksson et al; 2005) Therefore, one can say, the bigger the efforts on human capital, technology and R&D, the government makes aligned with the private sector needs the better will be for the production and development of the economy.

For Pyo (2005), the increased spending on R&D has been proved to lead countries to the discovery of new technologies and the development of new products that contribute to higher productivity (Pyo; 2005).

2.1 Relationship between engineers and growth

Economic growth is important because it creates basic conditions to achieve development. The lack of enough number of engineers matching the demand of labor force in the market, and the economic structure of the countries, cause problems such as less productivity and less production, importation of foreign human capital, unemployment and the economic growth in general is affected negatively.

Some studies have shown the relationship between the number of engineers and better economic growth and development. For example Murphy et al. showed that countries with a higher proportion of engineering college majors grow faster than those with higher proportion of lawyers which tend to grow more slowly (Murphy, et al.; 1991).

For Murphy et al. the lawyers are understood as rent seekers, and engineers as entrepreneur. They crossed data on college enrollments, and real GDP per capita between 1970 and 1985, plus more facts such as coups, revolutions, etc. and made a regression for 91 countries, founding a significant and also positive effect of engineers on growth, and negative and insignificant effect of lawyers on growth. Concluding that rent seekers reduce growth while entrepreneurs and innovators raise it up, therefore the growth is determined by the allocation of talent (Murphy, et al.; 1991).

A recent research paper, also found out how important was the initial number of engineers for countries to perform better than others in the Americas. Maloney and Valencia showed how the density of engineers in 1900 was key for some countries to grow faster or instead lost market share when the density was smaller (Maloney & Valencia; 2014). Indeed a relation between engineers density and income in 1900 was depicted by the author. For more information on this relation see the Appendix I.

The inability to use new technologies by well trained engineers made some countries lose competitiveness and even the control of strategic sector such as mining for some Latin American countries. The study also highlights the importance of innovative capacity and human capital investments for growth. In addition the study includes references to the types of institutions inherited from the colonialism period (slavery, extractive institutions, restrictions to receive education) and other reasons of that determined the engineering capacity in 1900 such as weather, population agglomeration, market size, and so forth, which actually will be out of the scope of this thesis (Maloney & Valencia; 2014).

Maloney and Valencia also found that the engineering densities in 1900 actually affect the outputs of today. They ran a simple correlation[13] between engineers' density and basic indicators related to inputs and outputs of modern days such as R&D/GDP,

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[13] Correlation between engineering density in 1900 and three inputs and two outputs in 2000. Inputs side: 1. R&D expenditure as a share of GDP. 2. Firm capacity for innovation ranging from pure licensing to pioneering their own new products and processes. "In your country, how do companies obtain technology? (1=exclusively from licensing or imitating foreign companies; 7 = by conducting formal research and pioneering their own products and processes) from Howitt, & Mayer-Foulkes (2005). 3. A globally measure of management quality from Bloom & Van Reene (2010) and in particular, the sum of the scores on the two questions dealing with how firms identify new production process to adopt. 4. Comin & Hobjin (2010); Comin & Ferrer (2013); Comin et al. (2008)'s measure of technological adoption at the extensive margin, averaging their industrial and sectorial scores. 5. Patent applications field under the Patent Cooperation Treaty (PCT) per million population as tabulated by the World Economic Forum (2008-9) from the World Economic Forum et al. 2012. The explanation is given at Maloney & Valencia; 2014.

firms innovative capacity, modern capacity for the input side, and for the output side, patents and technological adoption. The correlation results between the set of engineers they used from 1900 and those indicators mentioned is above 0.9, almost a perfect correlation (Maloney & Valencia; 2014). See the appendix for more information.

2.2. Relationship between quality of engineers, R&D and development

Tertiary education achievement in number such as the quantity of engineers required to satisfy the demand in the market is important, but the achievements in tertiary education quality represents as seen above opportunities to create well-informed and competitive business and companies, and so the quality of the education received will be also a determinant of the better economic performance. Quality of tertiary education means better jobs, better business and invents created, more probabilities of success, and even more revenue for the government.

If engineering is an attractive major, the quality of talent in engineering is higher, therefore entrepreneurs have higher quality, the rate of technological progress would be greater and the growth rate of GDP per capita would be higher too (Murphy, et al.; 1991).

In our modern times, the rise of government research institutes GRI, private research institutes, scientific academies, universities with close ties with industries[14] etc. push countries with

[14] The Republic of Korea provides good examples of this: The number of government research institutes surpasses 50 working in various areas. On the other hand, KAIST founded in less than 40 years has become on of the best universities on engineering, is a good case of industries related to industry needs.

a minimum level of skill to assume the modern R&D and advances coming from such institutions (Howitt & Mayer-Foulkes; 2002). Investing in these types of institutions is crucial to provide endogenous researches and developments required for the economic growth.

For Maloney and Valencia, the scientifically oriented human capital, and a technologically savvy entrepreneurial class – understood by Murphy as engineers-, was necessary to expand the stock of knowledge and convert it into local growth (Maloney & Valencia; 2014).

Therefore the lack of human capital – in our terms as lack of engineers and lack of good quality of engineers-, motivation for local R&D –starting with import of technology to understand and develop similar technology[15]- and infrastructure required for R&D to build and endogenous technological capacity, should be priorities for developing countries (Pyo; 2005)

The technological frontier in the world keeps advancing and becomes more complex therefore any country should increase its

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POSTEC that actually was found following the KAIST model was promoted by POSCO the main steal Korean company, among other cases can be found in Korea.

[15] Pyo explains that: technology buyers in developing countries are given multiple choices of different technologies by technology sellers in advanced countries for a given plant construction or processing know-how. Usually, the choice of the right technology at the right price and at the right time is the most crucial part of the success of the project. In the case of Korea, this role of choosing the right technology at the right time was left to entrepreneurs and engineers, not to bureaucrats. Most engineers were foreign-educated, and consulted domestic R&D centers to acquire knowledge of the technology in question. (Pyo; 2015)

engineering skills levels to try to catch up or at least survive in the economic market competition.

For those reasons it is assumable that the quality of engineers could be beneficial to better economic performance if the quality measured by the identified common outputs such as patents, publications in research papers, and also by other indicators as number of projects done by academy and private sector jointly, number of researches, etc.

For Maloney and Valencia, there are three types of countries regarding these matters: A first type are the countries able to undertake modern R&D thanks to their labor force which are likely to grow faster. The second type are other countries with too low skills to do R&D but at least able to imitate and absorb capacities from first movers which can continue in the economic market by implementing foreign technologies. And a third type represented by countries less imitation and absorptive capacity than the second type which as a result grow less and end up diverging. (Maloney & Valencia; 2014)

Skill acquisition aware of the technological change is fundamental for increasing productivity. Institutions that can facilitate the skill improvements and promote technological implementation are the proper ways to get to good rates of technological implementation to dissipate low technology traps. The lack of proper policies on human capital and technology policies made that by 1995, 33 countries were 50 years behind USA and 73 were more than a century behind (Howitt & Mayer-Foulkes; 2002).

In fact, for Acemoglu & Dell (2010) the sub-regional differences in incomes in Latin America, points out that human capital and technological advances are determinants of productivity differences among countries. (Maloney & Valencia; 2014).

In a different study about endogenous growth, Howit found that countries showing positive R&D investments could converge to parallel growth paths at the same of develop nations, while those who does not show R&D investment will tend to stagnate. The increase in the investment rate or the R&D-subsidy rate in any R&D producing country is similar to the economic growth rate behavior. At the same time the model run demonstrates changes on the income per person in the long run and influence world growth based on R&D levels (Howitt; 2000).

Such finds are aligned with many empirical studies demonstrating that large proportion of the economic growth in developed countries was thanks to improvements done in technology (mainly from innovations coming from research institutes) rather than the accumulation of capital (Aghion & Howitt; 1992).

But not only R&D is important to innovate and bring technological change for boosting the economic growth and increases the productivity. R&D is also important because the nature of our market is based in permanent changes seen in new consumer likes, new methods of production, new transportation, new markets in general pushing the economy to keep moving and at the same destroying or letting behind the old economic structure.

(Aghion & Howitt; 1992).

This last phenomenon was understood such as the process of creative destruction and this brings enormous implications for developing countries because in the nature of the market, a continuous process of changes and innovation have to be pushed through R&D. For infant economies, this process might have to be lead by government until conditions in the private sectors can take the leading in terms of funding. Having the right institutions and political stability (Pyo; 2005) (Rodrik: 2003) are also key determinants of successful outcomes from R&D. And also the message is that it would not be even enough to just imitate if we consider that the imitation will end up being replaced by the innovation adjusted to the markets needs and constant changes.

On this, South Korea is a good example of how to work on becoming a first mover after having almost no conditions to even follow. The Korean experience demonstrates that it is possible the transition from imitation to innovation (KIM; 1997). Whereas Latin American countries have experienced a scenario where few skills and low knowledge for labor force made potential sectors failed or bought by foreign firms[16].

[16] By the end of 19th century and beginning of 20th century, the mining in Mexico and Chile bring historical evidence of how important is this. In both cases, local entrepreneurs lost share in the industry dominated by them for centuries due to lack of adoption of emerging technologies invited by US, and not learning by doing to face the technological advances. Like these two countries, many other Latin American countries showed a shift from local production to stagnation in local industries, high dependency on foreign firms and imports of American and Europeans talents whilst human capital in Latin America was not formed to adapt. (Maloney & Valencia; 2014)

Regarding to imitation, some have defined it as learning by doing process and it has also positive impacts on the economic growth. In other words imitation is understood as the accumulation of knowledge by doing and best way to make it part of the economic growth process is by focusing in the time between innovations and jump there to compete and provide what others have invented – and haven't yet still changed or "destroyed" in terms of Schumpeter. In that moment the aim is to compete on manufacturing those products placed in the market with better quality and more efficiently produced than before. (Aghion & Howitt; 1992)

Regarding to innovation, for the Department of Industry, Science and Research of Australia innovation could be the most important factor to increase productivity (DIISR; 2011). Innovation is even more important for labor constrained economies because without its rate of growth will fall to zero. Plus, industries essential to economic growth like construction, mining, telecommunications or manufacturing requires good quality of engineers and by focusing on industries relevant to engineering, higher productivity and economic prosperity is expected (Engineers Australia; 2012).

Innovation and imitation are keys for economic growth because them help to increase the productivity. In the case of Colombia innovation is pending and imitation is paradoxically understood as something banned for young people who can become engineers in R&D. Inspire and motive school students since early ages to imitate for later innovate is key. In general, all what can be related to imitation has negative perception disregarding the importance of imitation for those counties placed behind in the tracks of economic growth and technological advancements.

However it is important to highlight that reverse engineering was tried in Colombia during some period between 70's and 90's when the import substitution policy started in Latin America. Based on a former director of COLCIENCIAS, the reverse engineering for imitation was tried but during the 90's the government remove the support for such work thinking that the private sector would become the responsible for future projects and pay for all the research products (Oppenheimer; 2010). Nevertheless, the industries were not strong enough to be in charge of and the outcomes of research were not all profitable or not aligned with industries needs, in addition, the government started the market liberalization during the beginning of 90's which make more easy to import and affect economically the local industries to invest in R&D and to the point where some of those had to close.

One of the ways to star the big push on these fields on innovation and imitation is by focusing on the quality of engineering. If working in all professions is suggested it will reduce the total impact of channeling resources towards producing highly and competitive engineers, considering the budget constraints and the important findings on how important are engineers for the economic growth.

In Colombia, already some industries highly dependent on good quality of engineers have been focused by government policies to increase the level of productivity and competitiveness, such as the cases of: auto parts and vehicles, software, ICT – information and communications technology, steel, shipyards, energy, etc.[17]

These days, one can identify two main strategies for the industrial development in Colombia: the *Locomotives* and PTP - *Productive Transformation Program*. The first one represent the main engines that will move the economic growth in Colombia based on its National Development Plan, PND –which is currently being updated since the President Santos has been re-elected and new plan will have to consider the new term. The main engines are agroindustry, infrastructure, mining and energy, ICT, and housing. The second national strategy refers to a program started in 2008 aiming sophistication and diversification of the industry. Some sectors were chosen as highly competitive and potential competitors worldwide. With those sectors the government works on regulations, infrastructure, financing, and more important for this study, human capital development to support those sectors[18]. Those two strategies are aligned with the importance of having better engineers that can supply the demand, innovate –or innovate- and boost the productivity and capacity of the majority of each of those sectors to bring more economic growth.

[17] In all these sectors South Korea had worked and have experiences to share however that industry approach level is out of the scope of this thesis.

[18] In Manufacturing: Cosmetics and personal care products, Editorial and graphic communication industry, Auto parts and Vehicles, Fashion system, Steel, Metal work, and shipyards. In Services: BPO, Software and IT, Electric Energy and Services, Medical Tourism and Wellness, Nature Tourism. In Agroindustry: Aquaculture, Beef and cattle, Chocolate, Candies and Raw Materials, Horticulture, Dairy, Palm, Palm Oil, and Biofuels. (MCIT – PTP; 2015)

Such strategies but even more importantly the fact that Colombia is an open economy, with good number of FTA signed, makes the country think urgently in how to increase the quality of our professionals, and as concerning to this study, the quality of engineers which could help the economy to face exogenous challenges.

Colombia has a large number of Free Trade Agreements, FTAs, among others, with US, European Union, Canada, South Korea, Chile, Mexico, Switzerland, Norway, Brazil and has some in negotiations such as the ones with Turkey and Israel. Indeed, in the Economic Forum Index, Colombia is ranked No 28 while countries such as South Korea, Malaysia, Spain, Mexico, France are behind, and this is partially explained by the opened market as one of the 4 components of the indicator (Index of Economic Freedom; 2015).

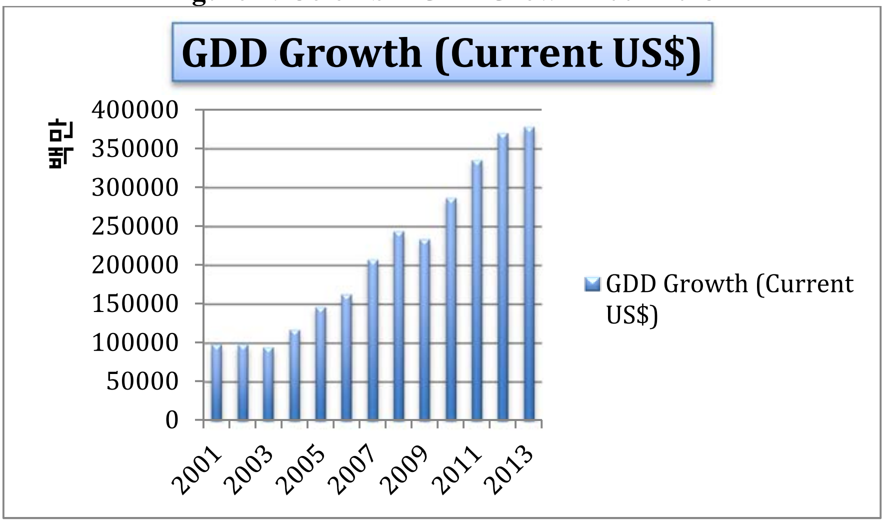
Having an opened economy plus already some selected sectors to push the economic growth, which in fact requires high technology, make even more urgent working on quality of engineers and scientists united with R&D investments.

3. Issue Background in Colombia

3.1 Macroeconomic Indicators

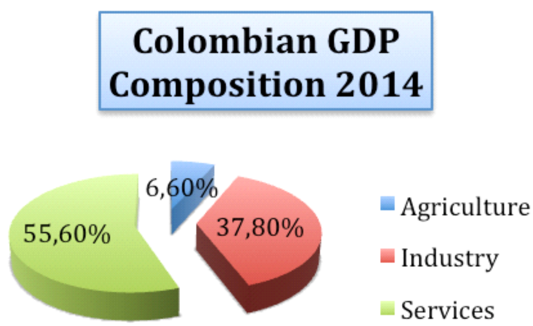
Before going to the numbers of engineers, it is important to mention that Colombia's GDP composition by sector is represented in 6,6% generated by the agriculture, 37,8% by industry, and 55,6% by services sector. Regarding employment by sectors in Colombia, agriculture sector represents 18% of the total employment, the industry 13%, and services 68%19. In addition, Colombia is an urbanized country: 75.6% is urban population (UNDP Human Development Report; 2012).

Figure 2: Colombia GDP Growth 2001-2013



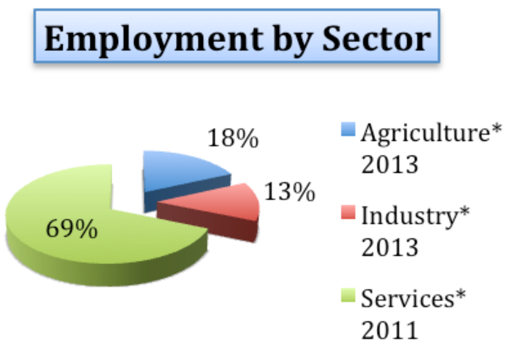
Source: World Bank.
http://databank.worldbank.org/data/views/reports/chart.aspx#s_e

Figure 3: Colombia GDP composition in 2014



[19] CIA, The world fact book. 2013 est. https://www.cia.gov/library/publications/the-world-factbook/geos/co.html

Figure 4: Employment by sector in Colombia



3.2 Tertiary (Higher) Education in Colombia

In overall, the net enrolment rate in tertiary education increased from 17% in 2002 to 24% in 2010. And currently is around 42%, but still some people feel that there is a wrong allocation of human resources being graduated in terms of the fields that should be selected to benefit the economic growth.

Colombia counts with 288 tertiary education institutions providing higher education programs. Each year, around 61% of students (approx. 1,3 million students) are doing professional programs while around 32% (approx. 700 thousand students) are doing technical and technological programs after ending high school. And SENA the Government biggest institution for training education (in 2013 received almost 400 thousand students) enrolls more than half of total students on technical and technologist programs. (Ministry of Education; 2014)

The following tree tables explain in details what has been mentioned above:

Table 2: Numbers of higher education institutions in Colombia. July 2014

Type of Institution	Public	Private	Special Regime	Total
University	31	49	1	81
University Institutions - Technological Schools	16	93	12	121
Technological Institutions	6	39	6	51
Technical Professional Institutions	9	26		35
Total	62	207	19	288

Source: MEN, SACES.

Table 3: Enrollment participation % and number by type of formation program

Type of Program	2005	2006	2007	2008	2009	2010	2011	2012	2013
Technical	11,4% (136.509)	13,37% (171.362)	15,08% (205.586)	14,99% (223.062)	11,8% 185.322	5,6% (93.014)	4,4% (82.406)	4,0% (78.942)	4,0% (83.483)
Technological	13,26% (158.781)	13,7% (175.690)	13,88% (189.233)	16,1% (239.584)	18,92% (297.183)	26,8% (449.344)	27,8% (520.739)	27,8% (543.804)	28,7% (604.410)
University	70,4% (842.482)	68,10% (872.902)	66,88% (911.701)	64,68% (961.985)	64,37% (1.011.021)	62,4% (1.045.570)	61,8% (1.159.335)	62,2% (1.218.536)	61,4% (1.295.528)
Specialization	3,84% (45.970)	3,7% (47.506)	2,99% (40.866)	3% (44.706)	3,49% (54.904)	3,6% (60.358)	4,3% (80.663)	4,2% (81.339)	3,9% (82.515)
Master	1% (11.980)	1,02% (13.099)	1,05% (14.369)	1,09% (16.317)	1,29% (20.386)	1,4% (23.808)	1,6% (30.360)	1,7% (32.745)	1,9% (39.488)
PhD	0,08% (968)	0,08% (1.122)	0,1% (1.430)	0,1% (1.532)	0,1% (1.631)	0,1% (2.326)	0,2% (2.920)	0,2% (3.636)	0,2% (3.800)
Total	100% 1.196.690	100% 1.281.681	100% 1.363.185	100% 1.487.186	100% 1.570.447	100% 1.674.420	100% 1.876.323	100% 1.958.429	100% 2.109.244

Source: MEN, SACES

Table 4: Details of technical and technological enrolments by year

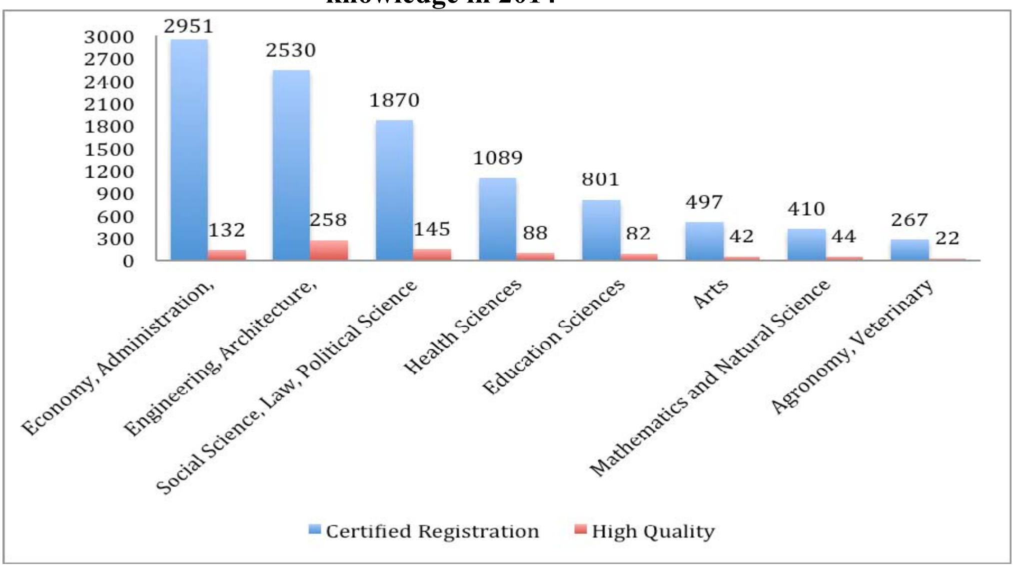
Type of Program	2010	2011	2012	2013
Total IES (Higher Education	245672	281184	287606	290594

Institutions)				
Private IES	121611	134552	148703	163886
Public IES	124061	146632	129903	126708
SENA	296686	321961	344140	397299
Technicians	26211	1024	5021	559
Technologist	270475	320912	339119	396740
Total	542358	603145	622746	687893

Source: MEN, SACES.

About the number of academic programs in tertiary education by field of knowledge, by 2014, the top 3 fields of programs, based on the knowledge area, are: 1) economy, administration, accounting, and related (with 2951 programs certified where 132 of those have high quality certification), 2) engineering, architecture and urbanism, (with 2530 programs certified where 258 of those have high quality certification) 3) social science, law and political science (with 1870 programs certified where 145 of those have high quality certification. In the next graph this can be observed in details:

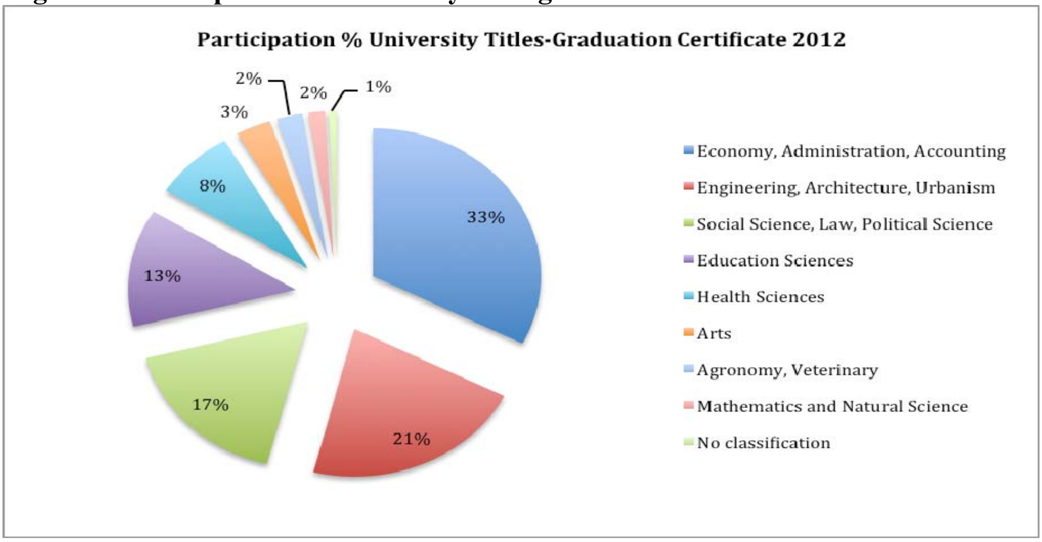
Figure 5: Number of academic programs in tertiary education by knowledge in 2014



Source: MEN-SACES- CNA. 2014

On the other hand the number of graduates by field of knowledge in 2012 was as shown in the next chart.

Figure 6: Participation % university titles graduation certificate 2012



Source: Labour Observatory for Education. Includes SENA graduates in 2012. The percentages are approximated.

From 2001 until 2012, the area with more graduates was economy, administration, accounting and others, while the second area is engineering, architecture, urbanisms, and others. The less number of graduates come from math and natural science and agronomy and veterinary. Not surprisingly, this matches with number of programs offered by field of knowledge: the fields with more programs have more graduates.

In 2013, those who studied engineering, architecture and urbanism were 27,8% out of the total. The trend as changed slightly since 2001, when the number of graduates was 30.756 (meaning 22,2%) and in 2012 was 66.539 (meaning 21,4%). There is also big change in number of students, where more students came to higher education and big change in number of programs where more programs where available to choose from thanks to big expansion of technical and technological programs.

In general, by 2013 almost 3 in 10, or 28% of graduates joining the labor market hold engineering, architecture or urbanisms program diploma or certification. There was an increase in more than twice in numbers of graduates on engineering, architecture and urbanism, and an increase by 6,4% in number of programs offered under that typology comparing years 2001 with 2013.

In the next section specifically engineering programs and engineers enrolled and graduates from professional, technical and technician programs will be considered to narrow down our analysis and be able to determine the real situation on engineering and its impacts on economic growth.

4. DATA ANALYSIS, EMPIRICAL MODEL, COMPARISONS AND FINDINGS ON ENGINEERINGES

4.1 Quantity of engineers: Supply and Demand from the education market at tertiary level institutions

Based on the SNIES – National Information System for Higher Education- of the ministry of education, the total supply of just engineering programs in 2013, in Colombia are 1829 programs including university degree programs, technological, and technical programs that fit under the umbrella of engineering, architecture, urbanism, and other related engineers. However, purely speaking about engineering and other related engineering are just: 1755 programs including undergraduate, postgraduates programs.

From those 1755 programs, 1431 programs are undergraduate programs (professional 1336, technical 52, technological programs 43) and 324 postgraduate programs (specializations 112, masters 165 and Phd programs 47).

In 2014 as shown above, the total number of programs for the field of engineering, architecture and urbanism was 2530, but in this section only engineering programs are focused: in 2013 only 1431 programs have in their main core of studies engineering, which is the heart of this study.

An example of how the data was handled is: there is a program, in the SNIES data, under the name of biomedical engineering that is part of the total engineering programs, however, we took it out because the main core of studies – *nucleo básico del conocimiento* in Spanish- or basic core of knowledge was medicine. Instead there are other 26 programs also called biomedical engineering offered by different institutions where the main core of studies is engineering.

Only 6 out of the 1431 programs (and also from the 1829) were provided by inactive (and also private) institutions, this means that those institutions cant receive more students and the program is inactive status. This means on 1425 programs were active in 2013.

All of those 6 were foundations allowed to provide technicians programs (*Formación Técnica Profesional*). In fact out of the 1431 programs, 89 programs are programs offering technicians and technologist programs (*Formación Tecnológica*). However we will consider, professional programs, technicians and technologist programs as one group because for some people these programs could be substitutes.

In the next graphs is depicted the trends on engineering enrolments and graduates from 200 to 2013, considering the type of education: professionals or technicians and technologist – were these last two types are shown as tec-techno.

Figure 7: Enrolled in first semester by type of formation at tertiary level between 200 and 2013 for engineering

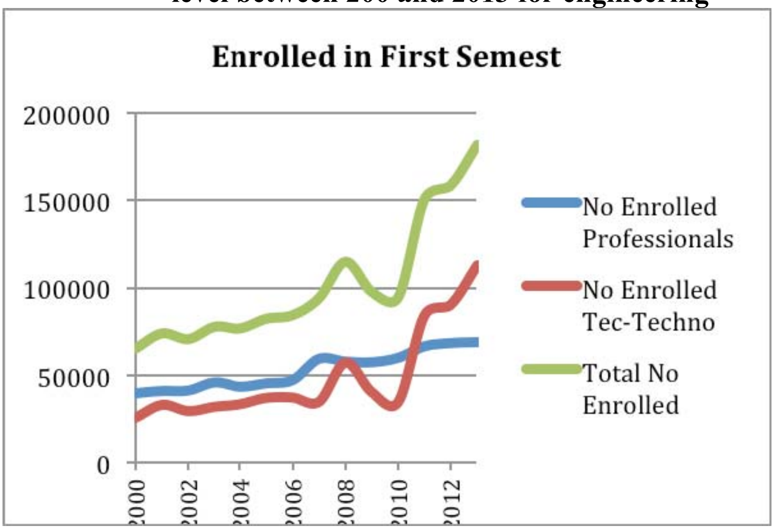


Figure 8: Composition of enrolled students by type of formation at tertiary level between 2000 and 2013 for engineering

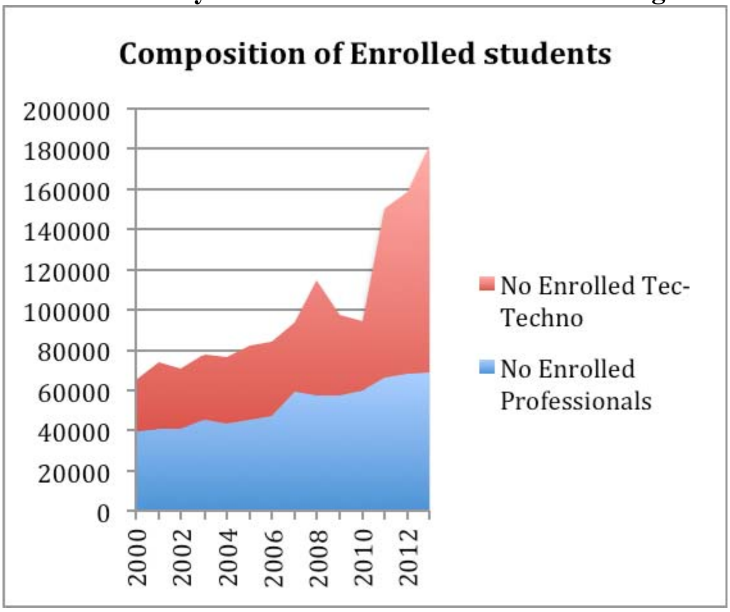


Figure 9: Number of graduates by year and by type of formation between 2001 and 2013 for engineering

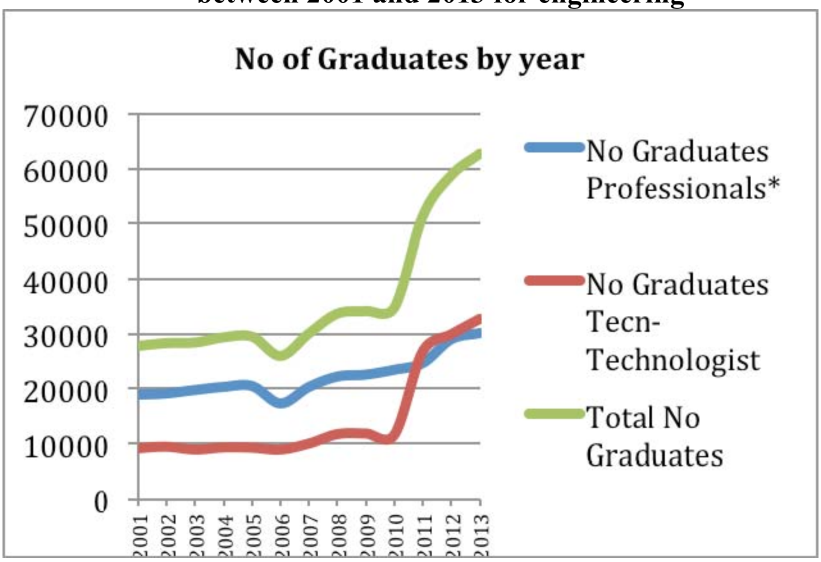


Figure 10: Composition of graduates by year and by type between 2001 and 2013 for engineering

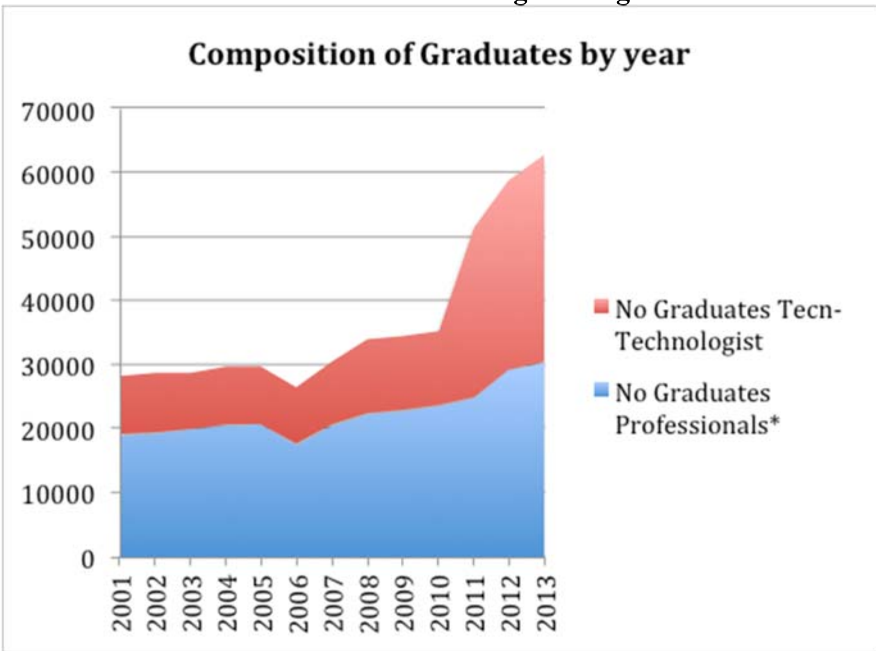
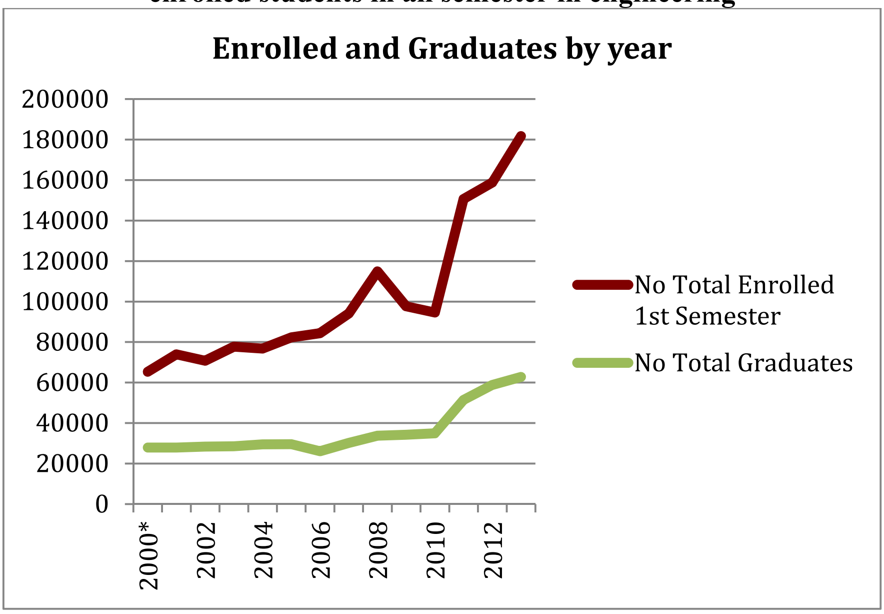


Figure 11: Enrolled students at first semester in engineering vs Total enrolled students in all semester in engineering



4.2 Engineering in comparison with other selected fields

It is very important to find how is the numbers of engineers enrolled and graduates standing in front of other common and popular fields also at specific level, meaning for example that law will be considered independently from its area of knowledge that includes social science and political science.

Table 5: No of enrolled students in selected fields and their participation on the total No of enrolled

Table: No of Enrolled students in selected fields and their participation on the Total No of enrolled								
Year	Total No Enrolled first semester *	Only Engineering Professional degrees**	Total Engineering Programs* **	Only Law Professional degrees**	Total Law Programs** *	Only Medicine Professional degrees**	Total Medicine Programs* **
2005	1137772	45320 (3,98%)	82332 (7,23%)	22257 (1,95%)	23452 (2,06%)	6987 (0,61%)	7136 (0,62%)
2006	1219954	47197 (3,86%)	84395 (6,91%)	22464 (1,84%)	23646 (1,93%)	8163 (0,66%)	8306 (0,68%)
2007	1306520	59347 (4,54%)	94148 (7,2%)	24998 (1,91%)	26335 (2,01%)	8788 (0,67%)	9129 (0,69%)
2008	1424631	57773 (4,05%)	114922 (8,06%)	23407 (1,64%)	24457 (1,71%)	8018 (0,56%)	8419 (0,59%)
2009	1493526	57417 (3,84%)	97707 (6,54%)	21941 (1,46%)	22658 (1,51%)	8290 (0,55%)	9173 (0,61%)
2010	1587928	23428 (1,4%)	94568 (5,9%)	25956 (1,63%)	26606 (1,67%)	9387 (0,59%)	10002 (0,6%)
2011	1762480	26760 (1,5%)	150692 (8,5%)	29075 (1,64%)	30738 (1,7%)	10105 (0,57%)	10458 (0,59%)
2012	1841282	29863 (1,6%)	158788 (8,6%)	34987 (1,90%)	36021 (1,95%)	9539 (0,51%)	10240 (0,55%)
2013	1983421	30147 (1,51%)	181762 (9,1%)	32203 (1,62%)	33683 (1,69%)	8760 (0,44%)	9377 (0,47%)

*Includes only University, Technicians, Technologists degrees
** Only University degree enrolments (also called professionals)
***Includes only University, Technician, Technologists

Concerning the enrolled students, from the table, a crucial finding can be indicated: Comparatively speaking among selected fields of knowledge, in Colombia since 2010 to 2013, the number of enrolled students and percentages (%) on engineering programs has been actually more than those for law and medicine programs.

In fact, when the number of enrolled students on technicians and technologists programs is deducted, the number of lawyers differs: from 2005 to 2009 the No of professionals enrolling for engineering was bigger. However from 2010 to 2013 the No of professionals enrolling was bigger. However, from the table we can assume that the change on professionals from 2009 to 2010 does not mean that people lost the interest in studying engineering. Instead it can been said that, from 2009 the number of professionals to 2010 suffered a decreased in half of its number because people might have understood that the market was looking for technicians and technologist and therefore a big increase in nominal numbers of students enrolled on technical programs occurred.

Somehow the numbers of engineers have been increasing at higher rates in comparison with other fields thanks mainly to technical and technological programs which was in fact a goal of the government during those years.

That finding is key because the policy makers and debate should not consider anymore the old assumption - until now- saying that people in Colombia decide to study more law than engineering. If the technologist and technicians are considered the assumption is not valid under the conditions explained above.

On the other hand it is worth to highlight that almost 10% of the new comers or entries in the higher education sector are choosing engineering programs, which is fundamental to boost the economic growth and therefore the development of the nation.

Regarding to graduate numbers of engineering, by observing the graduate numbers, one can conclude also that there have been since 2001 until 2013, in nominal number there has been always increases (except in 2006) and as a percentage of students graduating of engineering shows some minor decreases since 2008 while other non engineering graduates percentages gain those reductions. In the next table, this finding can be observed in details.

Table 6: Graduates in engineering and Non engineering in numbers and percentages from 2001 to 2013

Year	Graduates Eng	% Graduates Eng from Total Graduates (Eng Graduates + Non Graduates)	Graduates Non Engineering	% Graduates Non Eng from Total Graduates (Eng Graduates + Non Graduates)
2001	28339	25,38%	83338	74,62%
2002	29220	26,55%	80841	73,45%
2003	31081	25,05%	93019	74,95%
2004	33410	27,13%	89728	72,87%
2005	33410	29,45%	80024	70,55%
2006	30215	26,07%	85682	73,93%
2007	34590	26,00%	98450	74,00%
2008	36811	24,62%	112727	75,38%
2009	37790	23,33%	124216	76,67%
2010	37427	22,62%	128027	77,38%
2011	53589	23,53%	174198	76,47%
2012	60921	23,14%	202323	76,86%
2013	65372	23,83%	208999	76,17%

Source: MEN, Labor Observatory for Education

On the other hand, by looking into specific professions, it is possible to say that if engineers from different majors are considered as one group of engineers, they will be –one to one comparison- more than the numbers of lawyers, doctors and other fields, which was never admitted. Instead, articles, books, and in general the discussion has been always addressing why we had more lawyers and doctors than engineers graduating from tertiary level institutions. In the next table this could be confronted:

Table 7: No of graduate students in engineering in comparison with selected fields

Table: No of Graduate Engineers compared with selected fields

Year	Grad Eng	Only Eng Prof.	Law	Medicine	Economy	Administration	Political Science and IIRR	Education
2001	28339	18823	5923	2506	3591	22940	283	15954
2002	29220	19102	6634	2721	3350	21423	387	12136
2003	31081	19732	7653	3218	3297	23178	344	16907
2004	33410	20292	7740	3304	3562	22821	498	14003
2005	33410	20453	7442	3174	3310	20257	535	8129
2006	30215	17286	7459	3179	3495	19813	768	8590
2007	34590	20285	8990	3624	3841	24339	761	10983
2008	36811	22187	9697	3528	3812	25948	854	13651
2009	37790	22543	10138	3692	4505	29959	995	15709
2010	37427	23428	10345	4431	4636	30702	1096	15065
2011	53589	24660	11901	4404	6242	45613	987	18831
2012	60921	29003	13422	4874	7296	54818	1055	21550
2013	65372	30147	13579	5264	9739	61814	1162	20132

Source: MEN, Labor Observatory for Education

Those selected fields of knowledge were chosen because those are the ones commonly referred on any discussion about this matters, especially law, medicine and political science. The others were including because of the high numbers of graduates among the non-engineering graduates.

The important finding out of the table above is that even if we include other popular careers such as accounting, or business administration, and economy, we still can find that engineering is the one with more graduates. Only if we consider the number of professional on engineering vs. professional and technical and technologist on administration, administration could surpass engineering in terms of graduates. However when we also consider only the professionals from administration, the engineering professionals graduates remain higher in all fields. That is why we compare in the next table both professions regarding its professionals and technicians and technologist graduates.

Table 8: No of graduate students in engineering in comparison with administration

Table: No of graduate students in engineering in comparison with administration

Year	Graduates Eng	Only Eng Professionals	Administration	Only Admin Professionals
2001	28339	18823	22940	14352
2002	29220	19102	21423	14138
2003	31081	19732	23178	16372
2004	33410	20292	22821	16102
2005	33410	20453	20257	13711
2006	30215	17286	19813	14075
2007	34590	20285	24339	15485
2008	36811	22187	25948	16038
2009	37790	22543	29959	18041
2010	37427	23428	30702	19246
2011	53589	24660	45613	21750
2012	60921	29003	54818	26239
2013	65372	30147	61814	29394

Source: MEN, Labor Observatory for Education

Now lets see the total numbers of graduates in accumulation all graduates from the period 2001 to 2013 to have a wider picture of total human resources in Colombia coming from tertiary education institutions.

Table 9: Accumulation of No of graduates by selected fields from 2001 to 2013

Career	All except Postgraduate	Only University Degrees
Accounting	156681	115447
Business Administration	403625	234943
Economy	59271	44385
Engineering	503960	319182
Law	119333	112103
Medicine	45168	42926
Government and International Relations	1200	1200

Source: MEN Data

Only when accounting, business administration and economy graduates are gathered in one field of knowledge, engineering will be placed in second position as we saw above in the previous pie chart of graduates by title given considering the aggrupation of areas of knowledge, and also can be seen in the next table.

Table 10: Participation of graduation titles by broad areas of knowledge

Areas of Knowledge	Participation % Titles-Graduation Certificate 2001	Participation % Titles-Graduation Certificate 2012*
Economy, Administration, Accounting	31,7%	32,50%
Engineering, Architecture, Urbanism	22,2%	21,40%
Social Science, Law, Political Science	13,5%	17%
Education Sciences	18,2%	12,90%
Health Sciences	9,5%	7,80%
Arts	2,8%	3,40%
Agronomy, Veterinary	1,3%	2,50%
Mathematics and Natural Science	0.9%	1,60%
No classification	0,0%	0,80%

Source: Adopted from Labour Observatory for Education. *Include SENA 2012

The importance of making reference to this type of information grouped in broad areas of knowledge is because the information available from UNESCO is presented in the similar way to the information from the MEN but using different components in their aggrupation.

4.3 Country comparison

The UNESCO classification is interesting but does not allow us to go deeply into specifics on only engineering to make country comparison, however it is worth to bring next data.

Table 11: Comparison among US, Korea and Colombia on % graduates on engineering, manufacturing and construction

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Col	..	..	22,43	..	23,32	23,37	..	23,79	25,56	22,26	..	17,44	17,06
KOR	32,38	32,02	30,02	28,42	27,51	29,46	28,06	26,37	24,8	23,4	..	24,62	23,91
US	8,33	8,27	7,99	7,84	7,65	7,42	7,18	6,99	6,97	6,98	6,99	7,18	7,18

Source: UNESCO-UIS/ISU

The above table reflects why in US the debate is around the number of engineers, while in Colombia should be on quality terms. Many programs in US including programs to motivate students to choose engineering paths are implemented since kinder garden until 12 grades. This so-called K-12 education for engineering is also implemented for subjects such as science, technology and mathematics under the name of STEM schools. The goal is to increase youth interest on engineering and those fields. The debate in US should not be considered in Colombia since the numbers as proven before and also in these table from UNESCO date shows healthy numbers for the body of engineers required, instead, Colombia must focus on quality of its engineers, and one policy framework could be to invest more money and sources in 1 or 2 good performing universities on engineering or create a new specialized university if moving the quality up considerably seems to be difficult because of institutional constraints and internal rules that make difficult the focalization in the particular field of engineering and its desired outcomes on international comparably terms.

The importance of considering international standards to improve the engineering is gigantic: Colombia is an open economy as we mentioned before regarding its FTAs running and not only improvements on infrastructure will make the country more competitive, the education and specially the education of the engineers and scientists from Colombia should have high quality standards to be able to compete and help the industries to be competitive in front of innovation and developments happing around the world. If the human force is not able to introduce the permanent changes and innovation required by the market our industries will struggle or fail to survive unless they import the labor force able to suggest and introduce the changes needed in the industries to compete with world class industries.

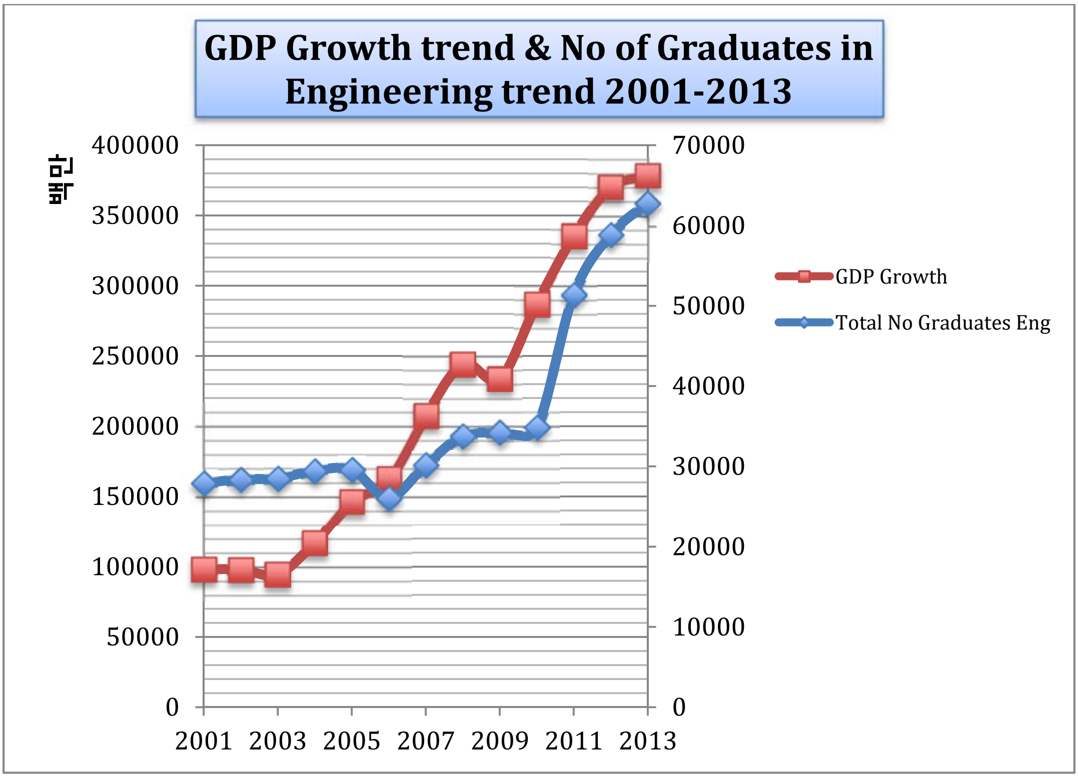
The other common policy frameworks to increase quality are by making agreements with international universities, and support with more funds the R&D in existing universities but those could be less effective considering the bias and structures at the back of such institutions, and the positive externalities such as bringing more competition on the existing universities to increase quality might be no achieved. These policy frameworks will be brought again and explained with its implications in the section of a positive change for tertiary education on engineering.

4.4 First signs of the positive relation on growth and engineering

Now what is concerning to the growth, the theories include in empirical studies the variable of graduates of engineering as a proxy to measure the impact of engineering in the economic growth. As seen before in recent studies such as the one done by Maloney & Valencia, the number of graduates in engineers was the variable considered to find how the density of such professionals impact the economic growth. The same can be told from Murphy study where the comparison between engineers and lawyers is based on graduates.

In our empirical study to be suggested in this thesis we start by looking the trend or shapes of the GDP growth and No of graduates.

Table 12: GDP growth trend & No of graduates in engineering trend 2001-2013



Source: World Bank Data. MEN
Note: GDP: Current US$ in Millions.

From the graph it can be seen how there are some similar moves along the trend curves for both variables: GDP growth and number of graduates. From 2014 to 2008, it is possible to see some increases at similar shapes. But more importantly, the period 2009 to 2013 where the line look to have almost the same slope upward.

Those movements on the curve could be interpreted as possible signs of the relationship among variables. However in this study we suggest in the next section a basic model based in a linear regression to determine to what extend the relationship is true.

4.5 Empirical Model

In this study, inspired on previous studies such as the ones done by Murphy, Maloney & Valencia, we will try to find how percentage of students with major in engineering has affected the economic growth in Colombia during the years 2001 to 2013. The challenge is huge because 13 observations is an small sample to consider but since there is no consistent and detailed information on specific fields of knowledge before 2000, the results with this sample could be a first step to bring interest in this issue and run the model in future years –and why not enrich the same model with more variables that could not be added because there are no consistency or no information for all years. The objective is to propose a basic model that allows us to draw some conclusion on the effects that percentage of students with major in engineering has over the economy.

Equation 1

$$\mathcal{Y} = \beta o + \beta 1 * x1 + \beta 2 * x2 + \beta 3 * x3 + \beta 4 * x4 + \beta 5 * x5 + \epsilon$$

Where

$\mathcal{Y} = Dependent\ variable = Economic\ Growth\ (GDP\ growth\ rate)$

$\beta o = Constant$

$\beta 1\ to\ \beta 5 = Coeficients\ of\ each\ independent\ variable$

$x1\ to\ x5 =$
$Independent\ variables = \%\ of\ engineers, trade\ to\ GDP\ ratio, inflation, unemployment, high\ technolog$
$\epsilon = Error\ term$

In this new model, different variables that might affect the economic growth (GDP growth rate), which is understood in our analysis as the dependent variable ($\mathcal{Y}$), have been considered. Previous models suggesting the importance of engineers included variables on coup d'état, demographic changes, patents, etc. Each of previous models (Murphy; Maloney & Valencia) have advantages and disadvantages on their considered variables, like this present study have too.

The dependent variables in our model are: ($x1$) considered as the percentage of engineers. In our model the percentage is taken considering that the whole group of engineers as a percentage might cause changes to economic while single individuals or number of engineers cannot influence changes in the dependent variable. The percentage of engineers come from the total of graduates having major in engineering in that year divided by the addition of total number of engineers graduated and the total number of non engineers graduated. The ($x2$) refers to trade to GDP or the sum of exports and imports of services measured as a share of gross domestic product GDP. This is considered because this reflects the openness to trade and therefore the availability to import foreign technology or final inputs from other economies that could be utilized or and adapted it to the local economy, and at the same time the access to other markets from industries that can enjoy economies of scale brought by engineers. The ($x3$) reflects the inflation in the economy, including then rate of price change in the economy or the deflation of the GDP from one year to another. The $(x4)$ represents the unemployment which can be linked with how the economy is growing with more or less generation of employment. The $(x5)$ denotes high technology exports out of total manufactured exports, understood typically as those products with high R&D intensity like electrical machinery, scientific instruments, pharmaceutical, computers and aerospace. All the variables are key for GDP growth and development.

4.6 Economic Model findings[20]

Table 13: Empirical economic model findings

VARIABLES	(1) GDP_Growth_rate
Percentage_Eng	0.361*
	(0.190)
Trade_GDP_ratio	0.631**
	(0.237)
Inflation	-0.654*
	(0.278)
Unemployment	0.547
	(0.357)
High_tech_export	-0.584*
	(0.262)
Constant	-0.279**
	(0.118)
Observations	13
R-squared	0.775

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[20] The STATA results shown of our regression give .the coefficient, standard error and the p-value.

From the regression made on the empirical model stated above we find important to highlight the next: There is significant relation in GDP growth rate and the percentage of engineers at P value smaller than 0,10 of significance level. With $\beta 1$ equal to 0,361 we could say that with 1% of increase of engineers the economy might show an increase in growth rate of 0,361. On the other hand as expected, the table is showing us the negative relationship between GDP growth and inflation because if the last one increases the GDP growth is affected negatively and therefore reduced.

For the group of all variables considered in the model, we found that its P value of 0,0315 is significant to the model. And the Adjusted R-Squared is 0,6139 implying that 61,39% of the variation in GDP growth can be explained by this model suggested, and the remaining 38,60% variation in the dependent variable is explained by the error term or ϵ.

Previous studies have found that there is positive relation on the percentage of engineers and economic growth as we have found for the 2001 to 2013 period in Colombia. However, an additional finding that might required further research is that more engineers might be no adding value to high technology exports. On contrary it might be jeopardizing the quality and competitiveness of such products that could be exported with very high valued added and all its implications for the knowledge economies of current days. We could say that the model is suggesting that more engineers were the reason of more economic growth but is that growth at the stage of the development of Colombia coming with more value added measured by the high technology exports –like computer, scientific instruments, aerospace, etc.- as a percentage of total manufactured exported goods? Is it just economic growth the ultimate goal for the stage of the economy of Colombia, which is considered as a high middle-income country? These questions are the perfect beginning of the next chapter where we insist that the discussion in Colombia should be shifting from more engineers to more quality of engineers.

Another explanation of the negative relationship in the technology exported and the economic growth could be that the technology exported is not cutting edge technology. In other words, it might be the results of imitation and in moments where the curve of price for those goods is decreasing because of two reasons: similar products are already being produced and exported by other countries which lowers the price, or maybe because increases in quality leads in short run reductions in prices. That's a pattern in current technologies specially the ones produced massively such as fridges, computers which are segments where Colombia competes with few considerably technological changes (OECD Manual Measuring Productivity; 2014)

Colombia is highly dependent in natural resources such as oil and it is know that based on the current "pozos" there will be only around 5 years of exploitation. This is a call to make changes and start investing in quality and able human capital to enter into the knowledge economics. Maybe some steps can be taken towards more highly qualified engineers that could face future changes in the economic structure and also able to add to the economy more value via products or outputs with high R&D channeled to current and new industries to bring a sustainable development.

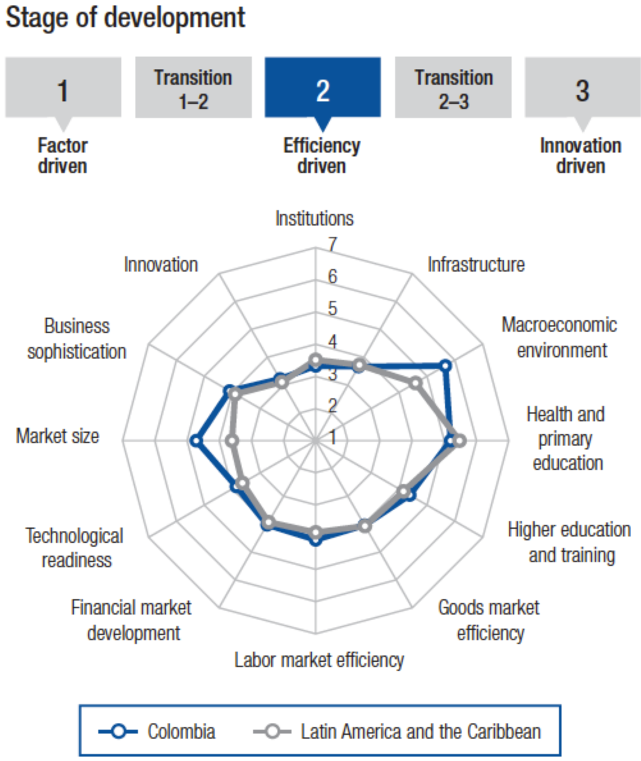
Besides the importance of quantity of engineers we rather focus in the quality of those graduates in particular from the engineering fields. In terms of quantity we must admit that the country has shown increases year after year on professionals and technical and technologist numbers of graduates, matching at some level with the economic growth shown and the market needs. At this point in Colombia considering the efforts done fro the government side enlarging the supply of engineering through SENA, the market should be the one driving the quantity upfront but the government in partnership with private sector should be shaping the quality and make the best efforts to increase it.

4.7 Qualitative findings: Based on international reports and studies

Measuring higher education quality is challenging. It is commonly used some proxies such as years of schooling or student professor ratio with many counterarguments but in this study we will rather focus on some reports and indicators that have been published by international organizations regarding to other type quality indicators or outputs usually linked with quality of higher education. In particular, as far as concern to engineering programs we will focus, on innovation broadly speaking to understand the stage of it in Colombia and the importance of improving it, number of patents considered as sign of innovation and are commonly accepted to be related to the number of engineers, scientists, and mathematicians, the number of research and academic publications in international journals which are associated with new ideas new trends that could be utilized by markets and industries, and of course international academic rankings for universities specially aligned with engineering degrees which as been the main area to focus in this work.

The current stage of development of Colombia says that the country has the challenge to advance two stages further. In other words the stage is in the middle of the track. Based on the Global Economic Forum report on Competitiveness for 2014, Colombia is at the *efficiency driven stage*, and needs to move to *transition 2-3 stage* and finally to *innovation driven stage* if wants to become a more competitive and prosper country.

Figure 12: Stage of development in Colombia and its factors by WEF



Source: WEF

As can be seen in the previous diagram, Colombia is showing how innovation is the worse graded component among the competitiveness indicators from the WEF. The importance of innovation, which is highly related and linked to R&D investments and quality of education, has been emphasized as key drivers of economic growth.

From the graph above is also possible to see how far is Colombia from the maximum frontiers (value 7) on innovation, and also in technological readiness and higher education and training and therefore the importance of working towards improvements on those sectors. (Global Competitiveness Report; 2014)

In fact, in a different and recent report on Human Capital, the WEF ranks Colombia not surprisingly with low values on innovation ecosystem indicators giving 3.71 in *State of cluster development* and 3.93 in *University-business R&D collaboration*, where 1 is the worst number and 7 the best in the surveys applied. (Human Capital Report; 2015)

On the other hand, the number of patents produced in the country is still very low to show signs of R&D and innovation. Regarding to the number of researches Colombia is showing some progress but still the numbers are very small yet.

There is not any university in the best 250 universities of the world. Not even by looking in engineers Colombia receives a proud position in international rankings. These are showing something important to work on.

In general, the innovation and R&D have not been prioritized but considering the capacities of the Colombian industries, having in mind the sectors selected in the PTP as competitive and winners to be fostered, the country should try a different approach and by focusing on engineering programs first, Colombia could push the quality up, and start closing gaps among countries with industries that relies on technology and constant innovation and so help local industries to survive in the long run and to become regional leaders.

The technology and innovation that engineers might applied into the industries can be seen in all sector, even in natural resources where some how Colombia has been benefit from without big or considered changes towards more competition. Just one month ago, Colombia sold 1 million barrels of crude oil to a Korean company that has the capacity to refine it despite its lack of such natural resource in its own land. This exemplify the importance of introducing changes in quality of engineers also in those sector that Colombia has seen for years as the backbones of the economy and the most profitable such as oil.

5. POSITIVE CHANGE AT TERTIARY EDUCATION LEVEL: Quality of engineers via the KAIST Experience

How to increase the quality of engineers considering the lack of a top-notch universities providing engineering programs in Colombia that can competitive with the best universities of the world, attract the best students to their programs and avoid brain drain? But also, how to guarantee world class engineers able to support the Colombian economic development and its industrial development in faster growth rates?

There are certainly various ways and some should be worked together, but in this thesis we want to suggest a robust and rich alternative, which could encompass many of the solutions: the creation of a world class university that pushes up the innovation level, the research and development needed to make the industries be more productive and competitive.

A good case of this is what has been done in South Korea with KAIST – Korean Advanced Institute for Science and Technology. Being an initiative of the national government, in less than 40 years KAIST has become the 51st ranked best university in engineering in the world based on the Shangai Ranking in 2014. Whereas none university from Colombia can be found among the best 200 from the Shangai Ranking in engineering neither in the best 500 in all fields[21].

By looking the QS World University Ranking 2014/2015, we can find that KAIST is also ranked as 51st best in the world. The QS ranking of top 50 universities with less than 50 years, places KAIST in the 3rd position in the world, and the 2nd best university based on the QS Asian University Ranking. What is more, in the QS World University Ranking by Faculty Areas 2014/2015 the KAIST engineering and technology faculty areas made it 17th in the world. Whereas the considered best two universities on engineering in Colombia, Universidad de Los Andes and la Universidad Nacional de Colombia are placed in ranks 368th and 278th respectively by considering the ranking by faculty on engineering and technology. In the world, Los Andes ranks 262nd considering all areas, and La Nacional ranks 316th.

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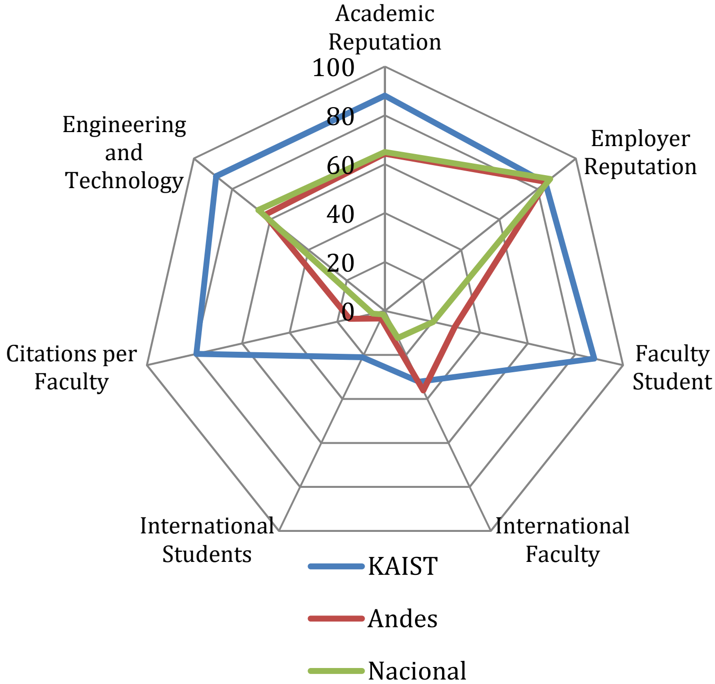
[21] The Shangai Ranking considers indicators on: Quality of education measured by alumni of the institution wining Nobel Prizes and Fields Medals (weight given to this indicator is 10%); Quality of faculty which is measured by staff of the institution wining Nobel Prizes and Fields Medals (20%), and also by highly cited researchers in 21 broad subject categories (20%); Research Output which is measured by papers in nature and science if applies (20% if does not apply the weight relocated in other indicators), and by papers indexed (20%), and per capita academic performance of an institution (10%) diving the above 5 indicators by number of academic staff, if the number of academic staff is not found the weighted scores above are used. For more info visit http://www.shanghairanking.com

In the next graph a comparison among KAIST, La Nacional and los Andes in suggested based on the 6 indicators used for the QS World University Ranking. Not all of those are directly related to the quality of engineers but still are shown to have a broad perspective on different areas measured by this index. Also, a 7th indicator will be added in the graph, which is related to the world ranking done by faculty, in this case, for faculties of engineering and technology. The ranking based on faculties does not publish detailed information per indicator, but positions are given and therefore are taken to compare the three universities only on their engineering and technology faculties. The graph aims to be illustrative and drawn some challenges by comparing the 3 universities[22].

[22] The QS World University Ranking is done by measuring: Academic reputation, based on global survey to academics (weighting 40%); Employer reputation, based on global survey to graduate employers (10%); Faculty/ student ratio (20%); Citations per faculty (20%); International student ratio (5%); International staff ratio (5%). In our graph, we added the axis of Engineering and Technology, which represent the ranking based only in Engineering and Technology. For more information visit: http://www.topuniversities.com

Figure 13: Radar graph based on QS World University ranking for selected universities



Analogously, the Times Higher Education ranking for 2014/2015 gives place KAIST as the 52nd best university in the world, but 26th in the top 100 universities for engineering and technology. However, for the Colombian universities, none university appears in the ranking considering only engineering and technology. Only if the Times World Ranking is considered, Los Andes appears ranked in the bracket of 251st and 275th. In the next graph KAIST and Los Andes are compared considering the World University Ranking indicators from Times Higher Education[23].

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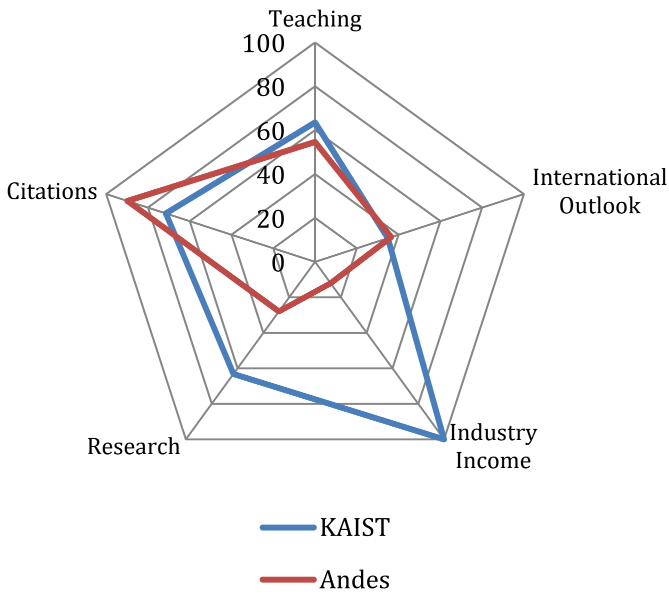
[23] The Times Higher Education ranking is done based on the 13 indicators grouped in the following 5 areas: Teaching, considering the academic reputation based on surveys, staff to student ratio, as proxy for teaching quality, doctoral to bachelors degree ratio as proxy for knowledge intensive environment, and

Figure 14: Radar graph based on Times Rankings for selected universities



Special attention can be given to the industry income indicator where KAIST gets 100, which is the maximum score, while Los Andes obtains 36,5. For Times ranking this indicator reflects the ability of the university and industry to work together

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institutional income scaled by academic staff number (weighting 30%); International outlook, students from abroad, ratio of international to domestic staff and research journal publications with at least one international co-author (7,5%); Research, considering research excellence survey done by peers, university research income scaled by staff number, and research output by staff numbers (30%); Citations, considering number of times of a publish work is cited by scholars globally, and taking in account that some areas are traditionally highly utilized for citations and balancing the weight among areas (30%); Industry income, considering the research income earned from industry by the number of academic staff it employs, reflecting the willingness to pay for research and development from the market and the ability of the university to attract that source of founding (2,5%). For more information visit https://www.timeshighereducation.co.uk/world-university-rankings which is understood as a core mission for the universities in current days.

5.1 Origins of KAIST

High skilled workforce in science and technology to lead the economic development was needed. Many talented students went abroad looking for quality. Highly capable scientist and engineers stayed abroad. In 1973 with a loan from US-AID, was build KAIS – Korea Advance Institute of Science to secured talented engineers by offering a world class institution, with laboratories, research facilities, scholarships for the best, research funds, dormitory and even exception from military service (usually only 3 weeks instead of 3 years by that time). Years after, KAIS was integrated with KIST – Korea Institute of Science and Technology making in 1981 a new institution called KAIST – Korean Advance Institute of Science and Technology.

Playing a key role providing initially PhD and Masters graduates –and later undergraduate students- KAIST has also increased the quality of engineers, improved the links with high schools focusing on science and technology and universities, with research institutes from public and private sector, with research departments of leading companies and industries, has fostered the interested of young people in science and technology, has supported the economic development and industrial development of South Korea, has prevented at some extend brain-drains satisfying short and mid term needs of R&D workers.

The 80s showed an increased urgency of having high quality engineers that could implement the plans to develop and boost strategic sectors such as chemical, steel, automobile, shipbuilding and electronics sectors, 4 of which are part of what Colombia has include in Productive Transformation Program, PTP.

An Education Act gave KAIST operational autonomy with an independent board of directors, self developing degrees, stable financial government support, no-department admission and no-examination system [24], flexible academic systems combining masters and PhD, early advancements to PhD, a research institute[25], equivalence system for credits in other universities of Korea, and other countries, among others. (R&D and technical education; 2011).

Its focus on engineering and economic development made the school be based on programs which thesis had to be thought for Korean industries. Therefore the school had also industry-academy programs receiving not only full time students but also workers of the selected industries. Korean scientists and engineers working in the United States played roles as full-time professors, research professors, adjunct professors and associate professors.

Despite the consensus on the necessity of establish a special engineering graduate school, the initiative had to be led by the

[24] It made it the first test-free admission university, considering only grades on math and sciences, recommendation letters from teachers, letter of interest and study plan.

[25] However, in June 1989, the research division of KAIST was separated again to KIST in July 1989, and KAIST survived with absorbing Korea Science and Technology University.

Ministry of Science and Technology because the strong opposition from Ministry of Education and Universities saying that it could threaten the future of existing programs in science and engineering universities. (R&D and technical education; 2011)

By 1989, KAIST had 2,581 students: 1,426 students in undergraduate programs and 1,155 students in postgraduate programs and more than 10 departments such as Mechanical Engineering; Industrial Engineering; Material Science Engineering; Electrical and Electronic Engineering; Chemical Engineering; Biotechnology; Aerospace Engineering; and Management Science. (R&D and technical education; 2011)

With KAIST ongoing, *chaebols –Korean big conglomerates*- on electronics also invested and channeled funds to build large-scale laboratories jointly run by the corporate personal and university body to develop joint research and developments. As an example, LG Electronics developed a joint laboratory and projects on digital measurement, factory automation and precision fabrication (KIM; 1997)

Since its origins KAIST was devoted to nurture the best engineers using science and technology to lead industrial developments need for the economy instead of producing Nobel Prize winners. (R&D and technical education; 2011)

KAIST started to fight also another issue: the brain drain and became good brain competitor for the best students and also best professors and researchers from Korea and abroad; in fact the university was created as tuition fee free university to attract the most talented young people and only around 2007 a Nobel laureate on Physics who was hired as President, suggested to move to a more privatized scheme. His main argument was that the budget allocated from the national government would not be enough to compete effectively against the best research universities such as MIT or Stanford. For him the graduate education would not be sustainable "without the cross-subsidy from tuition revenues generated by undergraduate students". The board did not accept the market-oriented proposal and his contract were not renewed. (Clotfelter; 2010)

Today, KAIST has 10,249: 4,047 students in undergraduate programs, and 6,202 postgraduate students. All its 14 departments are part of 5 colleges: College of Natural Sciences, College of Life Science and Bioengineering, College of Engineering, College of Liberal Arts and Convergence Science and College of Business.

5.2 Successful case led by KAIST and noteworthy

When the level of the economy of South Korea was still taking off, KAIST became crucial to develop key R&D projects that could push the economy up and help the economy in some extend to the point where now is one of the first movers in many industries.

By 1984 and 1985, KAIST led a strategic project on ultrasonic scanner technology that was funded by the government and one local medical equipment producer. With some time the local company step out of the project and KAIST understood the importance on making some changes such as find a new private partner for the project but also bring into the researches team two new members: an expert in marketing and other in venture business, to have a total of 7 researchers. They got 4 patents, published articles on international journals, and probably more telling Medison Company was founded. Today Medison is part of Samsung group and shows high level of technology and innovation in all its products and services. (KIM; 1997)

Today KAIST keeps being a pillar for R&D in South Korea. Its role to support specially those industries selected during the 70's and 80's to push the economy has changed. Now the companies and conglomerates from those selected industries have their one universities and own research centers while KAIST have more wide and transversal projects in different fields applying its good capacity to pursue studies, research and development at the best innovation quality.

Years after, KAIST was the model for other new special science and engineering graduate schools such as Pohang University of Science and Technology and Gwangju Advanced Institute of Science and Technology.

Another very interesting feature of KAIST is its programs in English to attack students and teachers foreigners that can enrich the environment of learning within the university. In fact, one of is goal stated in its vision is to provide all courses in English in order to achieve the highest quality of education, internationally comparable with other universities. In addition, the institution is trying to get a ratio of 6:1 students per professor, among others. While in Colombia, the some universities and stakeholders just justify the low position and almost non existing participation of Colombian universities in the best 300 universities arguing that the official language is Spanish not English and for them that is a big part of the reason of the low performance in the international rankings. Well, then the should look the Korean case and what universities like KAIST is trying to do to bring the best quality education to the nation, where they have a even a language nothing close to English.

5.3 Implications and expected outcomes if KAIST model is followed

The importance of having a university like KAIST relies in the importance of producing innovations for the market needs, producing academic researches but also stimulate the imitation when is it needed. Colombia could competitive industries where the innovation could be the goal, but there are also potential industries or intermediate industries where we have found potential and theirs maturity is not still strong to compete, therefore the imitation as a first step to move towards the innovation is needed.

There has been an interest on what could be done from the government side, the academia and private sector to encourage a better composition of education programs in Colombia in terms of the market needs. KAIST represents what the 3 sectors mentioned could support, being this an initiative led by COLCIENCIAS expecting to have strong opposition from the Universities as seen in the Korean case, or, if possible led by the Ministry of Education which has demonstrated in the last year revolutionary policies in the sector to increase the quality and competitiveness of Colombian education, and have stronger power to negotiate and persuade with arguments the expected opponents to the creation of the new university.

More competition to the universities who might feel fear at beginning will bring only an increase in quality of the entire sector, as it was mentioned before in this thesis. The competition is healthy and has been proven to push for more quality of developments and researches.

Somehow the harmonization of public and private sector has been worked through the SENA and some could ask why not to work this approach with this institution. The reason is that KAIST is completely different, the goals and the level of education differ. In the SENA only technical and technological programs are offered while the KAIST model works on graduates and postgraduates students looking for permanent innovation, through R&D.

The new institution to be built should have research and development university status like KAIST. The Vocational colleges usually produce patents that are "imitative that is, practical adaptations of existing technologies. In contrast, research universities may mainly generate patents for innovations at the frontier of technology" (Aghion et. al; 2010).

Part of the challenges that this alternative would face in Colombia is that current engineers might oppose to this new school that will be considered as the top best university in engineering. They might feel the new students could take their jobs from these universities but as counterargument the policy advisor of this type of measures can justify the importance of bringing competition to the universities today ranked in the best positions in Colombia. The market of engineering programs will have to introduce improvements via professor, facilities, agreements with international universities, investment in R&D projects and improving the relationship with the industrial sectors to launch initiatives jointly. Plus, overall the competition that the new institution could bring to the education market is fundamental to increase the level of outputs in the existing institutions.

KAIST received autonomy from its creation to implement policies and introduce changes within the institution. One of the reasons of why the new institution should have autonomy forming the new engineers is because based on previous studies the governance and autonomy affects the outputs in this case measure by patents and the position in research rankings from the world.

In EU countries and US, autonomy and competition have been found as a positively correlated factor with public university inventive outputs. That conclusion is for research universities or baccalaureate colleges. For 2-year colleges, known as vocational institutions the autonomy and competition does not show significant relations. The results on such studies regarding these two regions have demonstrated how funding channeled to the autonomous public universities facing more competition from private research universities stimulate more patents. (Aghion et. al; 2010).

Another reason highlighting the importance of introducing a Colombian version of KAIST is because this new institution will work on a graduate level to improve the relation at professional level between education and industry. Just 2 years ago the OECD, made an evaluation of the tertiary sector in Colombia and found important to improve the participation of employers in the curriculum design and also to the identification of competencies asked for the industries. In general the relationship between public universities and the industries were relatively weak and only few tertiary education institutions have the capacity to introduce changes in the curriculum and integrate the research activity with teaching. (OECD & WB; 2013)

At the same time, regarding to the funding, it is important to keep in mind the importance of beginning with few numbers of students to guarantee and select the best of the best. This could be affordable and free tuition could be evaluated. Part of the royalties enjoyed could be channeled to this initiative and COLCIENCIAS has already received and important role to design and implement policies to increase science and technology through the 10%[26] of the royalties generated per year. The framework is ready and if regions raise opposition to develop this initiative in the capital, it would be good to evaluate too if the university could be established in some different region to bring a balanced development as it was done with KAIST, which has the main campus in Daejon -4 hours away from Seoul.

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[26] Thanks to the Legislative Act – *Acto Legislativo* No 5 de 2011, the 10% of the General System of Royalties will be allocated to the fund of Science, Technology and Innovation.

If free tuition is not approved, other mechanisms such as subsides to support the direct costs of the education, or loans and grant schemes could be considered too. In this point it is important to remember the key role of the industries too and they could become supporters of this initiative as happened in the Korean case and in many worldwide known top universities.

Another reason for looking for quality improvements through the KAIST model in Colombia is because previous efforts on other approaches such as funding of government research institutes or universities were implemented but yet the results were not satisfactory. For Miranda the former Director of Colciencias, during the 70's Colombia tried that way but after applying reverse engineering the projects did not receive anymore funding from the government and the results were not aligned with the market needs to bring somehow capitalization or funding from the private sector to continue doing R&D. But the biggest mistake was to leave the infant research and develop to the market while US, South Korea have shown government commitments to fund such institutions that cannot rely on profits from the market. (Openhaimer; 2010)

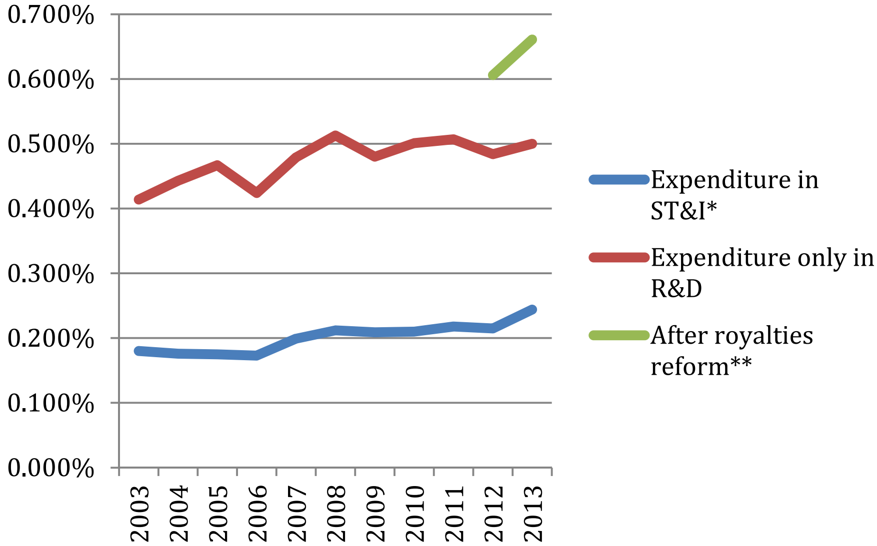
The classic approach of funding current universities was also considered in Korea but the fact that many of those universities have different agendas and priorities too make somehow lose impact on this types of goals where a new institution could build from the grounds the best environment and conditions to prosper in the challenging goal of quality and effective R&D.

KAIST was meant to be one university able shape the best engineers and scientists to supply the market with human manpower but also work with them and professor in top-notch projects that will be part of the graduation prerequisites.

Colombia needs to move the discussion into the field of quality of engineers and also the importance of scientists. In this work we do not go deeply on scientist as we did in the first part of this work with engineers, but models like KAIST will help the country to work in the direction of quality scientists too. For Isaksson, the technological change requires institutions support, open economy, and the existence of technological system composed by scientists, engineers, technicians and managers specialized in the development. (Isaksson et al; 2005) The first two seems to be ready; likewise the number of engineers, however, the quality should be improved through better institutions.

The situation on R&D is worrying despite some changes in the last decade in Colombia. The investment is still very small and the production of patents is very small in comparison with even countries from the same region. For a general ideal on this, the next graphs from the report *Indicadores de Ciencia y Tecnologia en Colombia*, portray the situation on investment, R&D sources types, fields of investments by socioeconomic objectives, R&D groups by fields, patents, and publications. (Observatorio de Ciencia y Tecnologia; 2013)

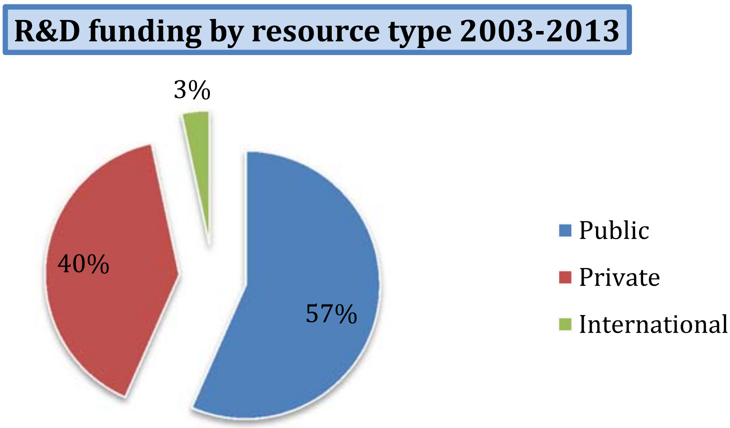
Figure 15: Expenditure in ST&I as % of GDP



Source: Indicadores Ciencia y Tecnologia; 2013
*ST&I refers to scientific, technological and innovation activities.
** Represents the increase due to projects approved under the new policy where 10% of royalties finance R&D.

The graph shows the low levels of investment in R&D in Colombia and the increased expected after the royalties reform began. Still, the investments on R&D are very low even comparing with Argentina and Mexico who invested around 0,4% in 2011, while in Colombia was 0,2%. Another issue, which is not part of this work, is how the new resources from royalties are going to be invested in the regions for R&D initiatives or if those will be broad activities somehow related with science and technology with low expected impacts for the innovation and development activities of the industries in the regions.

Figure 16: R&D funding by resource type average 2003-2013



Source: Indicadores Ciencia y Tecnologia; 2013

What is important to highlight from the above table is the resources funding R&D investments where in average 56,61% has come from public sector and 40,05% from private sector. 3,34% has come from international resources.

Table 14: R&D government funding by socioeconomic objectives

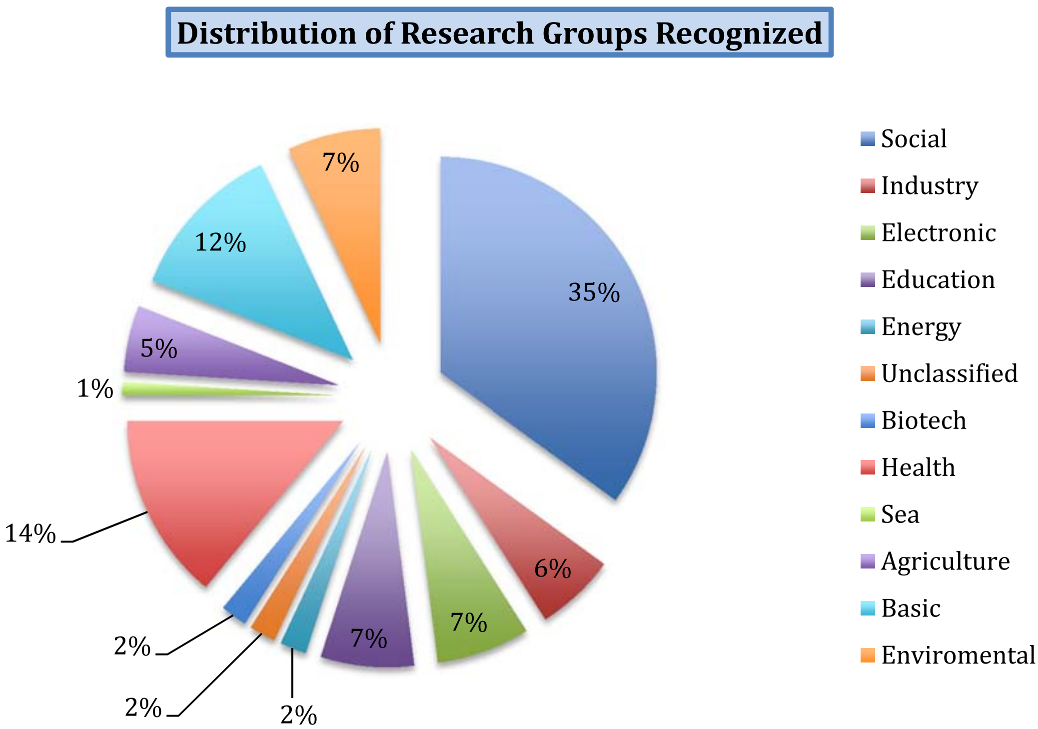
Socio Economic Objective	2011	2012	2013
Exploration and exploitation of the earth	17,56%	1,94%	31,07%
Environment	8,76%	11,08%	3,15%
Exploration and exploitation of space	0,80%	1,21%	0,82%
Transport, telecommunication and other infrastructures	0%	0,28%	1,12%
Energy	1,55%	3,16%	1,25%
Industrial production and technology	0,50%	0,75%	0,51%
Health	22,36%	32,44%	20,33%
Agriculture	18,19%	18,78%	17,74%
Education	0,36%	0,53%	0,36%
Culture, recreation, religion and mass media	5,14%	6,93%	4,47%

Political and social systems, structures and processes	5,34%	6,73%	8,37%
General advancement of knowledge	6,31%	9,50%	6,48%
Defense	13,15%	6,67%	4,32%

Source: Indicadores Ciencia y Tecnologia; 2013

It is clear how the R&D in oil sector as exploitation of earth has been a priority whereas telecommunications, energy, industrial production and technology all together do not match even with the investment in political and social systems. One can say that the R&D by socioeconomic objectives responds to the participation of the oil industry in the Colombian economy, however it does not match with ideal composition for the sectors selected to boost the economy such as shipbuilding, automobile, steel, etc.

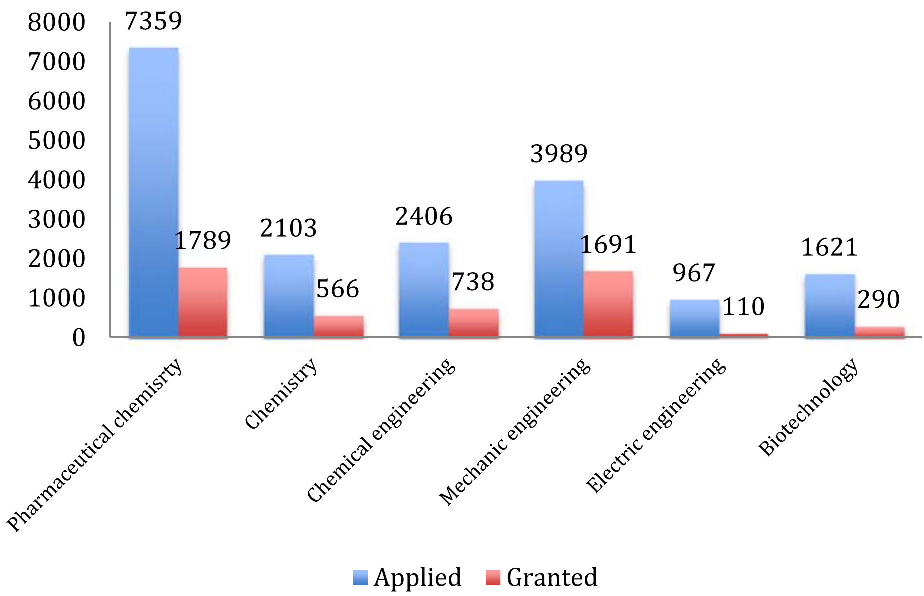
Figure 17: Distribution of Research groups recognized



Source: Indicadores Ciencia y Tecnologia; 2013. Training and Security are not presented in the above chart because the share of those two fields is 0%.

From the research groups' composition we can see that industry is not among the first 5 sectors, instead social amounted the highest share on research groups recognized officially.

Figure 18: Patents by sector from 2003 to 2012



Source: Indicadores Ciencia y Tecnologia; 2013

In patents during 2003 and 2012 we can see how chemistry, chemical engineering and pharmaceutical have played the most important role on applications and granted ones, while mechanical engineering gets the second position on granted ones during the 10 years period. Still the numbers are small in comparison with other countries and shows a concentration on a field where the outputs are not tighted with sectors defined as competitive and priorities under the PTP, productive transformation program. This shows, on other side, how important is the pharmaceutical industry in Colombia.

Table 15: Patents comparison with selected countries

Country	2008		2009		2010		2011	
	Applied	Granted	Applied	Granted	Applied	Granted	Applied	Granted
Colombia	2010	403	1752	479	1932	645	1981	629
Argentina	5582	1214	4976	1354	4717	1366	nd	nd
Brazil	26841	2778	25956	3138	28141	3617	22686	3251
Chile	3952	1398	nd	nd	1076	1020	2792	1013
Mexico	16581	10440	14281	9629	14576	9399	14055	11485

Source: Indicadores Ciencia y Tecnologia; 2013

In fact, Colombia reached the 3rd place in Latin America based on economy size in terms of GDP surpassing Argentina in 2014. The first has been Brazil and the second Mexico, however when we compare Colombia with other good performing economies and high GDP, we find that the production of patents as outputs of R&D is more smaller than expected.

Table 16: Publications comparison among selected countries

Country*	2008	2009	2010	2011
Colombia	3065	3136	3146	3095
Argentina	1195	1269	1381	1271
Brazil	5907	6254	6738	6926
Chile	933	1054	1091	1163
Mexico	3555	3819	3700	3952

Source: Indicadores Ciencia y Tecnologia; 2013.
* Refers to scientific articles in the journals included in REDALyC.

From the above table also from *Indicadores de Ciencia y*

Tecnologia of the Colombian observatory on science and technology a better performance can be seen in the case of Colombia, however the data should be considered carefully because it refers to some specific journals included in the journals of Latin America, the Caribbean, Spain and Portugal. That is why when US is included the number of its publications is only 668, and therefore being placed behind the selected countries of the table.

In Korea, the focalization of R&D in key industrial sectors was also aligned with strong education policy efforts such as expanding the numbers of graduates but also increasing their quality. Industries such as semiconductor, automobile and shipbuilding rely in science and technology policies, and today they are considered as success stories of how scientists and engineers played a crucial role to develop them. (LEE; 2012) Sectors as such has been selected in Colombia and no matching investment with those sectors can be seen yet in terms of investment, groups of research composition, patents, etc.

On the other hand, the research groups showed a big concentration on social science field and small in engineering. The patents in last years have aligned with the chemical industry, which is relatively strong in the region and has a good market position, but do not show alignment with electronic or mechanic engineering fields.

Likewise, regarding the research fields a non-healthy composition is seen for the sake of the industry development and economic growth in Colombia as mentioned before. Instead, Korea shows a different composition where material engineering, engineering display higher shares of citations (Lee et al; 2014) and big numbers of groups on R&D in engineering are established and leading the production of outcomes that foster the industries and the economy.

We could compare policies among countries in the region but the success story from Korea is meaningful for any developing country. The situation between Colombia and Korea was at some point close in challenges in this regards of R&D but different policy paths were taken and now we can see a big difference between the two countries were for example the numbers indicators on this matters have been widen. Some indicators regarding the two different evolutions on these matters are presented in the next graphs:

Table 17: R&D outputs in selected years Korea vs Colombia

Series Name	COL GDP per capita (current US$)	COL Scientific and technical journal articles	COL Patent application s, nonresid	COL Patent application s, residents	KOR GDP per capita (current US$)	KOR Scientific and technical journal articles	KOR Patent application s, nonresid	KOR Patent application s, residents
1960	252	..	..	..	156	..	66	545
1970	337	..	1041	152	292	..	644	1202
1973	450	..	709	76	426	..	776	1622
1980	1240	..	335	43	1778	..	3829	1241
1990	1209	122	..	..	6642	1170	16738	9082
2000	2504	332	1694	75	11948	9572	29179	72831
2001	2421	316	432	65	11256	11008	30898	73714
2002	2376	356	858	54	12789	11735	29566	76570
2008	5405	575	1818	126	20475	21091	43518	127114
2009	5105	608	1551	128	18339	22280	36207	127316
2010	6180	692	1739	133	22151	24106	38296	131805
2011	7125	727	1770	183	24156	25593	40890	138034

2013	7831	..	1781	251	25977	..	44611	159978

Source: World Bank (For more year series and GDP per capita information since 1973 check the appendix)

Two things can be underline about the above table: first, the GDP per capita in 1973 when KAIST started was only 427 USD while in Colombia was 450 USD. The allocation of sources in R&D has been growing year by year, and in 2014 it around 6% of the GDP being the one of the countries with more investments in R&D while in Colombia is less than 0,5% of the GDP. Second: Not all the outputs related with R&D can be related to KAIST, but it is accepted in Korean literature and among scholars that KAIST played a pillar role for the development of Korea, its industries and its R&D sector. The competition among universities, the focalization of resources, brought results for the economic growth of Korea.

6. CONCLUSION

Measuring growth requires a longer sample period than 2001 to 2013 because economic growth is a long-term phenomenon. In Education at tertiary levels the results in quantity cannot be counted in less than 2 or 5 years depending on the level of education. The data set available from MEN could be short to be mathematically highlighted. Despite of that it could be demonstrated at some extended how much it engineering affected growth in current days under the model depicted in this work. Others studied mentioned above have already proved the positive relation on engineers and growth, but the discussion should consider the quality side of this human capital inputs to the economy.

It was found based on secondary data provided by the MEN, that engineering when it is looked as an independent field of knowledge represents the field of knowledge with more graduates in the country in recent years, thanks in some years to the latest expansion on engineering education at technical and technological level which we value also as critical for economic growth.

The quality is the pending issue, and from the Korean case, it is possible to learn that the provision of education outside conventional frameworks is effective. The promotion of KAIST under the supervision of the Ministry of Science and Technology made possible the implementation of projects and programs that could not be implemented if regular frameworks apply. The lack of resources to work with all engineering universities at the same time made the focalization in one new institution a successful approach. The competition brought to existing universities, the autonomy given to the new institution created to push the quality of engineers and scientist and deployment of R&D projects aligned with the industrialization level of the country made KAIST a model to evaluate at early stages of innovation and technology adaptation.

The path chosen by Korea is worth to understand and follow under our present conditions and institutions, to make the proper positive changes needed to bring better performance in economic growth, and help the local economy achieve the steps to catch up the followers of first movers in the race of growth and innovation, through education policies that increase quality of determinant professions and R&D levels in the country.

The investment on R&D in Colombia has been very small throughout the years. Other challenges as security, education and public infrastructure issues might have called the attention and priority of the government. However, still countries under international security risks, or poverty levels and low infrastructure such as South Korea during the 80's took the risk and prioritized on R&D and education policies at tertiary level despite other challenges in other sectors to face too, now, the results and differences among countries are remarkable. In addition, the R&D in Colombia is not aligned with the sectors with potential and the sectors defined as competitive since 2008 are not showing higher movements on R&D and neither in outcomes but some can say that is still early to see outcomes. In terms of allocation of sources as a measure of inputs, some can say that there is no alignment between the sectors selected and the current expenditures. The groups of R&D are still composed by groups focusing on social sectors where the benefits can be smaller than the ones able to get if the R&D focuses on the industries where competitive advantages have been found. The alignment between government and private sector to boost the R&D utilizing the manpower on engineers and improving their quality is urgent. The Colombian economy is exposed to other countries that invest more and more in R&D and become more competitive even in sectors where the comparative advantages are in the Colombian side. Relying in natural resources is risky, and now as before and every oil crisis the country is suffering from the low international prices. The R&D will make the industry to rely on education and local capacity of its people, and at the same will increase the productivity of the local industries which are ready to compete in the region and further, but if no changes on R&D are introduced some years after they might disappear. The market is changing and innovating every day, and the only way to catch up is by imitating and then looking for innovate to the point of becoming first movers as Korea demonstrated that is possible. A big push from the institutions to motivate the quality of engineers and increase the interest on R&D and make it a priority in the national agenda through institutions such as KAIST or other alternatives is the message left in this thesis after showing the clear relation between engineering, R&D and productivity and economic development.

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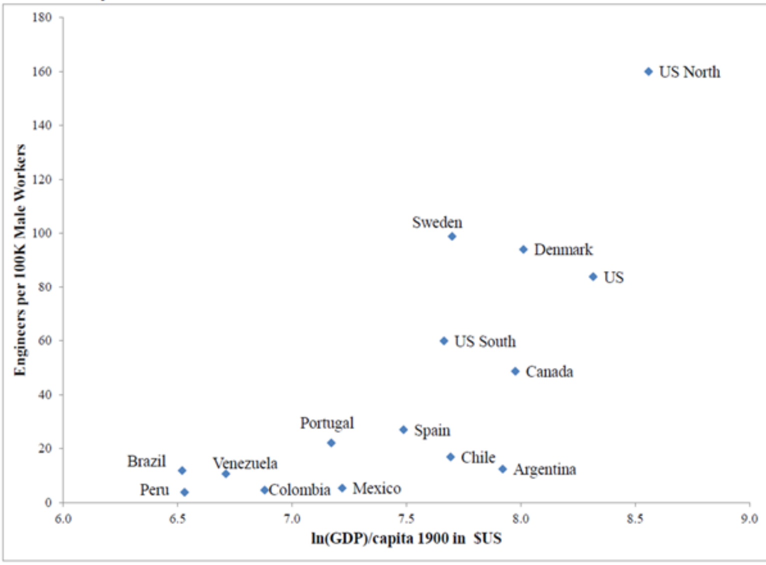
8. APPENDIX

Appendix 1: Income in 1900 and engineering density in 1900 (Maloney & Valencia; 2014)



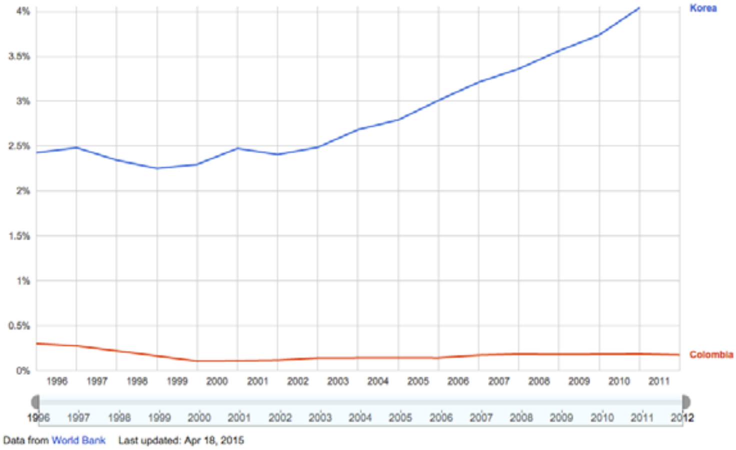
Source: From Maloney & Valencia; 2014.

Appendix 2: Mechanisms through which engineering in 1900 drives income in 2000 (Maloney & Valencia; 2014)

	All	New World
Inputs		
R&D/GDP	0.94	0.96
Firms innovative capacity	0.94	0.94
Modern management	0.93	0.93
Outputs		
Patents	0.95	0.98
Technological adoption	0.84	0.94

Source: Taken from (Maloney & Valencia; 2014)

Appendix 3: Research and development expenditure as % of GDP



Source: WB data.

Appendix 4: R&D outputs Korea vs. Colombia since 1973

Series Name	COL GDP per capita (current US$)	COL Scientific & technical journal articles	COL Patent applic, nonresid	COL Patent applic, residents	KOR GDP per capita (current US$)	KOR Scientific & technical journal articles	KOR Patent applic, nonresid	KOR Patent applic, residents
1973	450	..	709	76	426	..	776	1622
1974	527	..	619	50	589	..	3362	1093
1975	546	..	574	69	646	..	1588	1326
1976	625	..	555	67	875	..	1825	1436
1977	775	..	549	69	1106	..	1962	1177
1978	904	..	449	55	1468	..	3026	989
1979	1061	..	375	45	1858	..	3688	1034
1980	1240	..	335	43	1778	..	3829	1241
1981	1321	..	604	39	1969	168	3984	1319
1982	1383	..	..	..	2076	..	4368	1556
1983	1345	..	527	82	2268	..	4795	1599
1984	1299	..	471	69	2474	..	6636	1997
1985	1160	..	441	72	2542	424	7883	2702
1986	1138	90	404	81	2906	516	9115	3640
1987	1160	88	532	52	3628	672	12186	4871
1988	1225	86	420	85	4813	771	14355	5696
1989	1211	111	516	90	5860	1035	16295	7020
1990	1209	122	..	..	6642	1170	16738	9082
1991	1214	106	527	85	7676	1361	14880	13253

1992	1424	125	575	120	8140	1759	15122	15951
1993	1583	122	769	138	8869	2184	15044	21449
1994	2275	145	867	124	10275	2931	17158	28554
1995	2529	162	1093	141	12404	3803	19271	59228
1996	2609	195	1172	87	13255	4771	21921	68405
1997	2814	235	1497	80	12197	5802	25325	67359
1998	2552	248	1670	161	8134	7057	24637	50596
1999	2197	240	1615	68	10432	8478	24672	55970
2000	2504	332	1694	75	11948	9572	29179	72831
2001	2421	316	432	65	11256	11008	30898	73714
2002	2376	356	858	54	12789	11735	29566	76570
2003	2261	326	1127	82	14219	13403	28338	90313
2004	2753	359	1365	76	15922	15256	34865	105250
2005	3393	401	1662	99	18657	16396	38733	122188
2006	3713	470	1861	142	20917	17910	40713	125476
2007	4664	489	1862	128	23101	18470	43768	128701
2008	5405	575	1818	126	20475	21091	43518	127114
2009	5105	608	1551	128	18339	22280	36207	127316
2010	6180	692	1739	133	22151	24106	38296	131805
2011	7125	727	1770	183	24156	25593	40890	138034
2012	7763	..	1848	213	24454	..	40779	148136
2013	7831	..	1781	251	25977	..	44611	159978